PB86-161254

Chemical Processing Plants, Summary Report for Technical Support in Development of a Revised Ozone State Implementation Plan for Memphis, Tennessee

Pacific Environmental Services, Inc., Durham, NC

Prepared for

Environmental Protection Agency, Atlanta, GA

Jun 85

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB86-161254

Chemical Processing Plants, Summary Report for Technical Support in Development of a Revised Ozone State Implementation Plan for Memphis, Tennessee.

Jun 85

PERFORMER: Pacific Environmental Services, Inc., Durham, NC.
Contract EPA-68-02-3887

SPONSOR: Environmental Protection Agency, Atlanta, GA. Region IV.
Final rept.

Sponsored by Environmental Protection Agency, Atlanta, GA. Region IV.

The document presents information on emissions of volatile organic compounds (VOC) from chemical processing facilities in Shelby County, Tennessee. Information is presented on the industry, emissions from chemical processing plants, emission control techniques, and the costs of reducing emissions. Sources of information include trip reports prepared following plant inspections, discussion with plant representatives, documents prepared by the U.S. Environmental Protection Agency, technical literature, and information submitted by the plants for the Shelby County 1985 VOC Emissions Inventory. The control measures described in the document represent the presumptive norm or reasonably available control technology (RACT) that can be applied to existing chemical processing plants.

KEYWORDS: *Air pollution control, *Organic compounds, *Point sources.

Available from the National Technical Information Service, SPRINGFIELD, VA. 22161

PRICE CODE: PC A06/MF A01

PB86-161254

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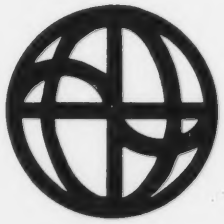

PACIFIC ENVIRONMENTAL SERVICES, INC.

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SPRINGFIELD, VA. 22161

CHEMICAL PROCESSING PLANTS
SUMMARY REPORT
FOR
TECHNICAL SUPPORT IN DEVELOPMENT
OF A REVISED OZONE STATE
IMPLEMENTATION PLAN FOR
MEMPHIS, TENNESSEE

Mr. Ron McHenry - Project Officer
U.S. Environmental Protection Agency
Region IV
EPA Contract No. 68-02-3887
Assignment No. 13

Pacific Environmental Services, Inc.
1905 Chapel Hill Road
Durham, North Carolina 27707

June 1985

DISCLAIMER

This final report was furnished to the U.S. Environmental Protection Agency by Pacific Environmental Services, Inc., Durham, North Carolina 27707, in fulfillment of Contract No. 68-02-3887. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the U.S. Environmental Protection Agency or of cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the U.S. Environmental Preotection Agency.

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1.0 INTRODUCTION AND SUMMARY

This document presents information on emissions of volatile organic compounds (VOC) from chemical processing facilities in Shelby County, Tennessee. Information is presented on the industry, emissions from chemical processing plants, emission control techniques, and the costs of reducing emissions. Sources of information include trip reports prepared following plant inspections, discussion with plant representatives, documents prepared by the U.S. Environmental Protection Agency, technical literature, and information submitted by the plants for the Shelby County 1985 VOC Emissions Inventory.

The control measures described in this document represent the presumptive norm or reasonably available control technology (RACT) that can be applied to existing chemical processing plants. Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of achieving by application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. However, short-term evaluation programs are considered an appropriate technology forcing aspect of RACT.

Reasonably available control technology for chemical processing plants in Shelby County will achieve at least an 85 percent reduction of VOC emissions from most major uncontrolled process vent streams. The implementation of a program to reduce VOC emissions from process equipment leaks will achieve between 32 and 100 percent control depending upon the type of equipment. Total emission reductions upon implementation of RACT are estimated to be at least 5,400 Mg (6,000 tons) per year from process vent streams and 300 Mg (330 tons) per year from equipment components.

2.0 PROCESSES AND POLLUTANT EMISSIONS

2.1 INDUSTRY DESCRIPTION

The chemical processing industry defined for the purpose of this document includes any facility that manufactures organic compounds or utilizes organic compounds in the manufacture of various end products. This broad definition encompasses a wide variety of manufacturing processes and end products, however, it associates facilities with similar sources of VOC emissions (discussed in Section 2.3) and applicable control techniques (discussed in Chapter 3.0). To illustrate the diversity of facilities in Shelby County, Tennessee, included in this source category, Table 2-1 provides a partial listing of companies, their processes, and the end use of the products they manufacture. These facilities are further described below.

A large chemical processing plant in Shelby County is the E.I. DuPont de Nemours & Co. (Inc.) facility whose principal product is methyl methacrylate (MMA). There are three domestic producers of MMA: DuPont, American Cyanamid, and Rhom & Haas. American Cyanamid and Rhom & Haas each have one manufacturing location at Fortier, Louisiana and Deer Park, Texas, respectively. DuPont has two manufacturing locations, the plant in Memphis, Tennessee and Belle, Tennessee.[1] In addition to MMA and acrylic sheeting, the DuPont Memphis plant produces six inorganic chemical products, and employs approximately 1,000 people.[2]

In early 1985, the manufacture of pesticides at the Velsicol Chemical Company Memphis plant was operating far below capacity. The chlorendic anhydride sources was operating at 34 percent of design capacity (down from 37 percent in 1984), and the heptachlor process was not running (down from 27 percent of capacity in mid-December 1984). The Velsicol Memphis plant also manufactures hexachloropentadiene, and sells various formulations of the products manufactured on-site with solvents and with chlordane received from the Velsicol Marshall Plant in West Virginia. The Memphis plant employs approximately 190 workers.[3]

Another type of chemical processing plant in Memphis is Buckeye Cellulose, the sole proprietor of the cellulose derivative product

Table 2-1. PARTIAL LISTING OF THE ORGANIC CHEMICAL PROCESSING INDUSTRY IN SHELBY COUNTY, TENNESSEE

Company	Process	End Products
E.I. DuPont de Nemours & Co. (Inc.)[a]	methyl methacrylate	acrylic sheet, surface coating resins, molding and extrusion powders, and emulsion polymers (for adhesive, leather, paper, polish, sealant, and textile applications)
	sulfuric acid recovery	sulfuric acid
	acrylic sheeting	bus windows, motorcycle windshields, safety glazing, lighting fixture lenses, sky lights, and signs
	hydrogen peroxide	hydrogen peroxide
Velsicol Chemicals Company[b]	chlorendic anhydride	pesticide formulations
	heptachlor	pesticide formulations
	hexachloropentadiene	pesticide formulations
Buckeye Cellulose[c]	cellulose derivative product	absorbent: surgical packs
	carboxy methyl cellulose	thickening ingredient: detergents
Plough, Inc.	granulation, tablet and gum polishing	Correctol,® Digel,® toiletry products
	aerosol can filling and degassing	
Shulton, Inc.	deodorant filler, can filling and degassing	deodorant, toiletry products

[a]References 1 and 2.

[b]Reference 3.

[c]Reference 4.

(CLD). Another plant process, carboxy methyl cellulose (CMC), however, is manufactured by other companies as well. At the beginning of 1985, neither process was in operation as the company was searching for new customers for their products.[4]

Plough, Inc. and Shulton, Inc., are two Memphis facilities that manufacture a myriad of well-known consumer products. Although these facilities are not specifically manufacturing chemical products, they do consume significant quantities of organic compounds for use in their production or as product ingredients, for example, as propellant to aerosol cans. Hence, these companies are discussed in this document because the sources of VOC and applicable controls discussed in the following chapters are similar to that of more characteristic chemical processing plants.

2.2 PROCESS DESCRIPTION

Process descriptions are presented in this section for a few of the chemical processes in Shelby County that are potential sources of VOC emissions. The process descriptions presented herein reflect either general or schematic representations for the plants presented in Table 2-1 (specific plant operations for these plants are not presented to protect proprietary information).

2.2.1 MMA Production[1,5]

The production of MMA proceeds through two sequential processes: (1) production of an intermediate product acetone cyanohydrin (ACN) and (2) the production of MMA from ACN.

ACN is produced by reacting acetone and hydrogen cyanide in the presence of a catalyst. The resultant ACN is neutralized with sulfuric acid and distilled. The ACN from the still bottoms are stored at reduced temperature (to prevent ACN from decomposing) and acetone vapors are recovered and recycled.

Production of MMA proceeds by hydrolyzing ACN with sulfuric acid in the presence of a polymerization inhibitor to produce methacrylamide sulfate. Water and methanol are reacted with the methacrylamide sulfate in an esterification vessel yielding crude MMA and spent acid. The crude MMA is separated and purified, and the spent acid is treated in a sulfuric acid recovery plant. The reactions describing this process are as follows:

acetone + hydrogen cyanide ----> ACN

ACN + sulfuric acid ---> methacrylamide sulfate

methacrylamide sulfate + methanol ---> MMA + spent acid

A full discussion of MMA production can be found in Reference 1.

2.2.2 Hydrogen Peroxide[6,7]

Hydrogen peroxide can be manufactured using the alkyl anthraquinone auto oxidation method. A 2-alkyl anthraquinone is dissolved in a solvent, then mixed and reacted with hydrogen in the presence of a catalyst to produce the corresponding anthraquinol or anthrahydroquinone. The anthraquinone solvent mixture (called the working solution) containing the anthrahydroquinone is separated from the hydrogenation catalyst and aerated with an oxygen containing gas (e.g., air) to reform the anthraquinone and simultaneously produce hydrogen peroxide. The crude hydrogen peroxide is extracted with water and purified by distillation. The extracted solution is recycled. Figure 2-1 presents a schematic flow diagram of hydrogen peroxide manufacture using the alkyl anthraquinone process.

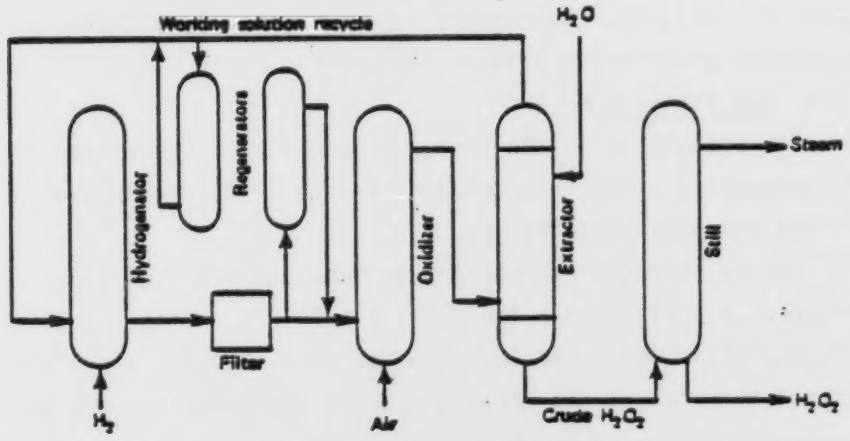

Figure 2-1. Schematic Flow Diagram of Hydrogen Peroxide Manufacture Using the Alkyl Anthraquinone Process[7]

2.2.3 Chlorendic Anhydride[3]

Chlorendic anhydride is manufactured in a series of batch operations by (1) reacting maleic anhydride, hexachlorocyclopentadiene (HEX), heptane,

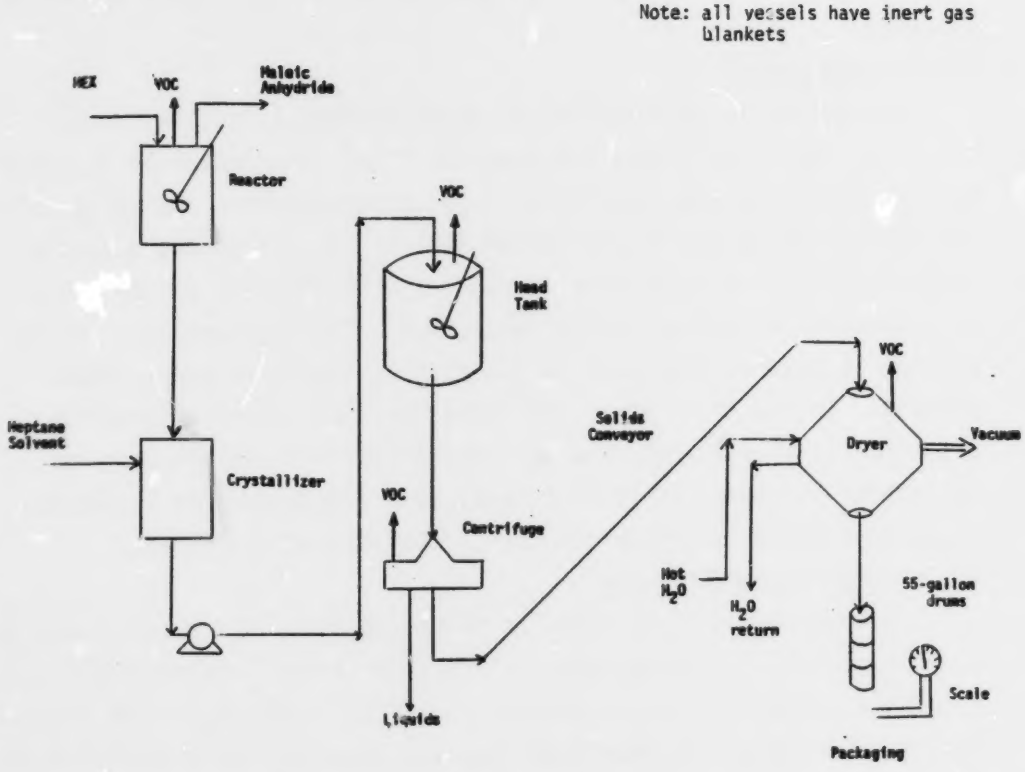

Figure 2-2. Schematic of the chlorendic anhydride process.

and toluene to form a chlorendic anhydride slurry; (2) crystallizing the slurry in solvents; (3) separating the solids from the liquid solvents (and subsequent solvent recovery for distillation and reuse); and (4) drying and packaging the solids as finished product. Chlorendic anhydride is stored in 250-pound fiberglass drums in a bag packaging area. Figure 2-2 presents a flow diagram of the chlorendic anhydride process.

2.2.4 Heptachlor[3]

Heptachlor is manufactured by batch process in several steps. In the first step, raw material heptachlor "237" is produced by reacting HEX, heptane, and propylene oxide with cyclopentadiene and by dissolving the mixture in carbon tetrachloride (CCl_4). In the second step the heptachlor "237" intermediate is reacted with chlorine in the presence of a catalyst to produce crude heptachlor. The hydrogen chloride by-product is absorbed and sent to the PCl plant as feed for the HEX process. In the third step, the heptachlor/catalyst/CCl_4 solution from chlorination is filtered, and the heptachlor is dried and packaged. Heptachlor is stored until it is weighed and packaged for shipment. Figure 2-3 presents a flow diagram of the heptachlor process.

2.2.5 Hexachloropentadiene[3]

Hexachloropentadiene (HEX) is manufactured by the chlorination of cyclopentadiene in two separate chlorination steps. In the first chlorination step, chlorine gas and cooled cyclopentadiene are reacted. Excess chlorine gas is separated from the intermediate product, PCL-2. In the second step, PCL-2 is again reacted with chlorine to yield crude HEX, which is then distilled to yield the HEX product. Figure 2-4 presents a flow diagram of the HEX process.

2.2.6 CLD and CMC Processes[4]

In the CLD and CMC processes, cellulose is ground, chemically treated and reacted, dried, and pulverized. Methanol and isopropyl alcohol (IPA) are used in the manufacture of CLD as a carrier for the product. The intermediate products are insoluble in organic compounds. Similarly, IPA is used in the CMC manufacturing process as a carrier.

2.2.7 Consumer Products

Specific information regarding individual plant production of consumer products in Memphis, Tennessee, is not easily addressed due to

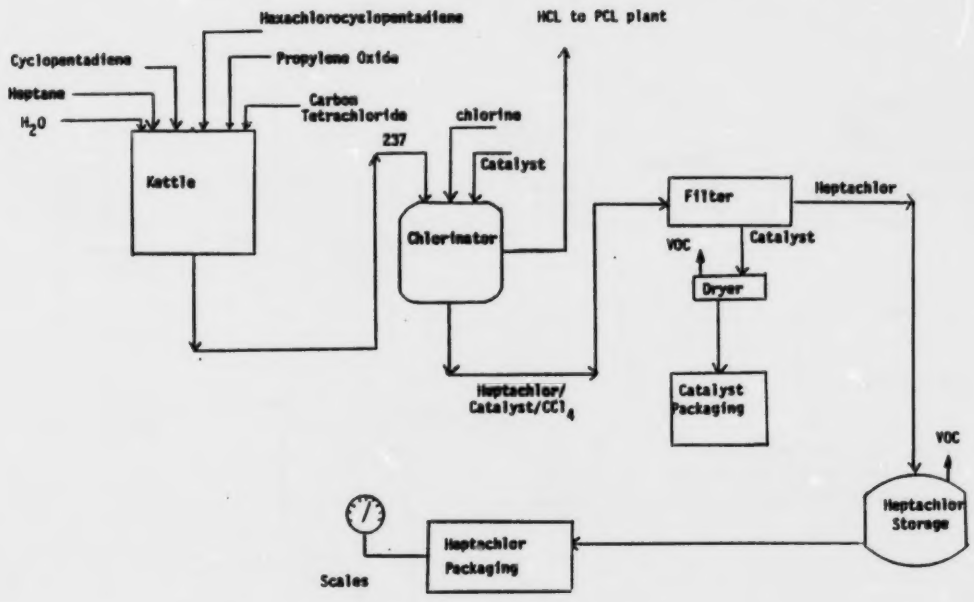

Figure 2-3. Schematic of the heptachlor process.

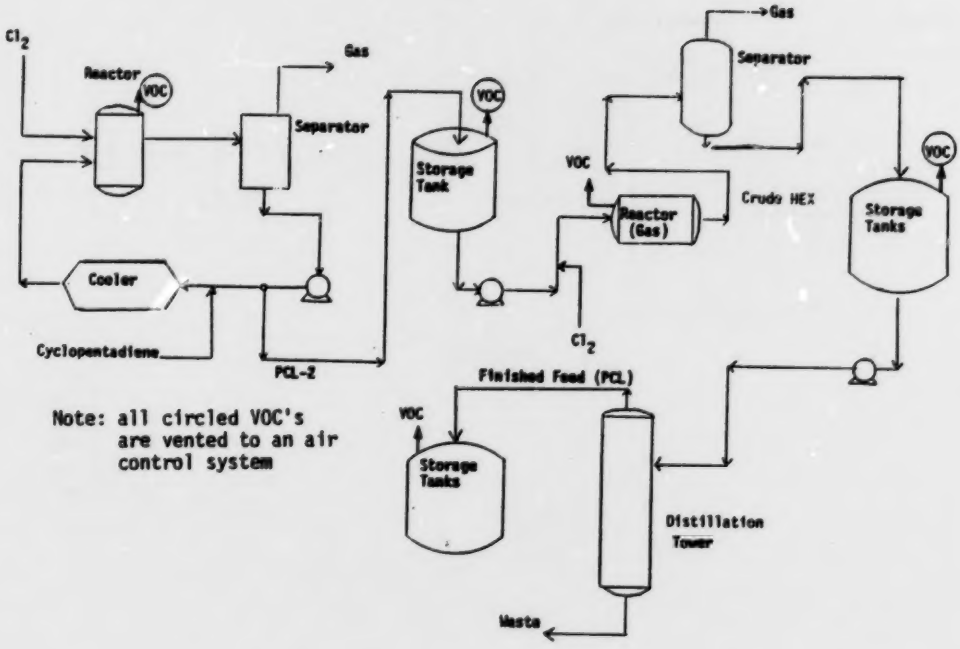

Figure 2-4. Schematic of the hexachloropentadiene (HEX) process.

the proprietary nature of the industry.[9] Therefore, a very brief overview of three processes common to such plants is provided. Granulation of powdered ingredients typically involves the use of organic carriers which are removed upon drying. Hydrocarbons such as propane, isobutane, and n-butane are commonly used as propellants for aerosol products.[10] Aerosol can contents are loaded by any of several methods (e.g., cold filling, pressure filling, undercap filling). Today, with sophisticated rotary machines with multiple filling heads, over 300 cans can be filled per minute.[10] Plants that fill aerosol cans may also have degassing equipment to puncture and recover can contents (e.g., products with expired shelf-life or leaking valves).

2.3 SOURCES OF VOC EMISSIONS

Despite the variability in the chemical processes described in Section 2.2, sources of VOC from the chemical processing plants are similar. The major emission sources, process vents, are presented in Section 2.3.1. The other group of emissions, equipment leaks, are discussed in Section 2.3.2.

2.3.1 Process Vents

Process exhaust gases released to the atmosphere from chemical processing plants may contain significant quantities of VOC. Table 2-2, a partial listing of process vent streams from chemical processing plants in Shelby County, identifies the VOC constituents in the exhaust gases and maximum annual VOC emission rates. The magnitude of VOC emissions from process vents ranges from a trace (e.g., streams not listed in Table 2-2) to over 3,000 Mg/yr. Exhaust gases may contain a mixture of organic compounds or single organic compounds (e.g., methanol). The plants listed in Table 2-2 reflect the variability in process vent emissions from those facilities listed in Table 2-1. Process vent streams from Plough, Inc. and Shulton, Inc., and many other chemical processing plants not specifically listed, fall within this range of VOC emissions.

2.3.2 Equipment Leaks

Common to all chemical processing plants are the equipment components used to move and control the flow of process fluids (both gaseous and liquid) to and from process vessels. Equipment components represent potential VOC emission sources whenever they handle a process

Table 2-2. PARTIAL LISTING OF THE CHEMICAL PROCESSING PLANT VENT STREAMS

Process	Vent Stream	VOC Constituents in Exhaust Gases	Maximum Annual VOC Emissions, Mg/yr (tons/yr)[a]
MMA	Crude MMA separation vessel vent	ACN, MMA, methanol[b]	3,266 (3,600)
Hydrogen Peroxide	Process vents[c]	Aromatic solvents, heptane aliphatic alcohol	1,415 (1,560)
Chlorendic Anhydride[b]	Reactor condenser vents[c]	Maleic anhydride, hexachloropentadiene, toluene, heptane, and chlorendic anhydride[d]	66 (73)
Heptachlor	Process vent	Carbon tetrachloride[d]	959 (1,057)
CLD[e]	IPA scrubber vent	Isopropyl alcohol	38 (42)
	Methanol scrubber vent	Methanol	266 (294)
CMC[e]	Fabric filter	Isopropyl alcohol	38 (42)
	Packed absorption vent	Isopropyl alcohol	3.8 (4.2)
		Total	6,052 (6,672)

[a] Reference 8.

[b] Reference 5.

[c] Several vents.

[d] Reference 3.

[e] Reference 4.

stream containing organic compounds. Equipment leaks may develop after some period of operation due to the failure of sealing mechanisms. Equipment types include pumps, compressors, valves, flanges, and safety/relief devices, open-ended lines, and agitators. The EPA has published several background documents that discuss in detail, studies conducted to assess equipment leaks in the synthetic organic chemical manufacturing industry.[11-14] Table 2-3 presents emission factors for chemical plant equipment components.

2.4 MODEL PLANTS

In order to estimate emissions, control costs, and environmental impacts for chemical processing plants, model process vent streams and plant equipment populations were developed. The five model process vents developed reflect the range of type of VOC constituents in process emission streams qualitatively and quantitatively. Model vent streams I, II, and III represent process emissions of light alcohols from process dryers and from a scrubber vent. These model vent streams would be typical of those found, for example, at Buckeye Cellulose, Plough, Inc., or the Shulton, Inc. facilities. Model Vent IV represents a chlorinated hydrocarbon such as that of the heptachlor process at Velsicol Chemical Company, and Model Vent V represents a large exhaust vent containing a mixture of hydrocarbons. Model Vent V typifies emissions from sources such as the DuPont MMA process. The model process vent streams are discussed further in Chapter 5.0 and in Appendices C, D, and E.

The model plant equipment component counts presented in Table 2-4 are typical of emission source populations that may exist at chemical processing plants in Shelby County. Model plant emissions from equipment leaks are estimated in Table 2-5. Model plant equipment counts were obtained from the model plants presented in the background information document for the synthetic organic chemical manufacturing industry (SOCMI). Some chemical processing plants, however, have very few equipment components (i.e., less than the number of equipment components presented for Model Plant A). The emissions and RACT impacts for such plants, for example, Plough, Inc. and Shulton, Inc., are not represented by the model plants. Instead, Appendix F of this document discusses the impacts for plants with relatively few equipment

Table 2-3. EQUIPMENT LEAK EMISSION FACTORS

Equipment/Service	Emission Factors[a] kg/hr/source
Pump Seals	
Light Liquid[b]	0.0494
Heavy Liquid[c]	0.0214
Valves	
Gas	0.0056
Light Liquid	0.0071
Heavy Liquid	0.00023
Compressor Seals	0.228
Safety/Relief Devices - Gas	0.104
Flanges	0.00083
Open-ended Lines	0.0017
Sampling Connections	0.0150

[a] Reference 12, p. 1-4.

[b] Light liquid is defined as a fluid with vapor pressure greater than 0.3 kPa at 20°C. This vapor pressure represents the split between kerosene and naptha.

[c] Heavy liquid is defined as a fluid with vapor pressure less than 0.3 kPa at 20°C.

Table 2-4. EQUIPMENT COMPONENT COUNTS

Equipment Component	Number of Components Per Model Plant A[a]	B[b]	C[c]
Pump Seals			
Light Liquid Service	8	24	160
Valves			
Gas Service	99	172	900
Light Liquid Service	131	228	3,000
Safety/Relief Devices			
Gas Service	11	34	100
Open-Ended Lines	104	318	1,400
Compressors	1	0	5
Flanges	600	1,830	7,400[d]

[a] Based upon Model Unit A of reference 11, p. 5-5.

[b] Based upon 400 valves per plant. Other equipment count estimates were proportioned to the valve-to-component ratios used in Model Plant A. of reference 11, p. 5-5.

[c] Reference 11.

[d] Based upon Model Unit C of reference 11, p. 5-5.

Table 2-5. MODEL PLANT EQUIPMENT EMISSION ESTIMATES

Equipment Component/Service	Emissions per Model Plant[a], Mg/yr A	B	C
Pump Seals			
Light Liquid	3.4	10.2	68.0
Valves			
Gas	4.8	8.2	43.3
Light Liquid	8.0	13.9	183
Safety/Relief Devices			
Gas	9.8	30.4	89.4
Open-Ended Lines	1.5	4.6	20.5
Compressor Seals			
Gas	2.0	0	9.8
Flanges	4.3	13.1	52.8
TOTAL	33.8	80.4	466.8

[a] Based on 8,600 hrs/yr.

[b] Example calculation: Model Plant A pump seals:

$$\left(\begin{array}{c}\text{Model Plant Count,}\\ \text{from Table 2-4}\end{array}\right)\left(\begin{array}{c}\text{Component Emission}\\ \text{Factor, from}\\ \text{Table 2-3, kg/hr}\end{array}\right)\left(\frac{8{,}600\ \text{hrs/yr}}{1000\ \text{kg/Mg}}\right)$$

$$(8\ \text{pump seals})\ (0.0494\ \text{kg/hr})\left(\frac{8{,}600\ \text{hrs/yr}}{1{,}000\ \text{kg/Mg}}\right) = 3.4\ \text{Mg/yr}$$

components. The model plant emission estimates given in Table 2-5 show that equipment leaks from a large chemical processing plant may exceed 400 Mg VOC per year.

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3.0 EMISSION CONTROL TECHNIQUES

Volatile organic compounds used as solvents, carriers, or key raw materials in chemical manufacturing processes, are emitted to the atmosphere from two major source types, process emissions and equipment leaks, as discussed in Chapter 2. Process VOC emissions can be reduced by emission control devices or by a process modification such as VOC recovery. Equipment leaks of VOC can be reduced or essentially eliminated by implementing a leak detection and repair program or by the use of specified controls or leakless equipment. This chapter describes emission control techniques that may be used to reduce VOC emissions from chemical processing plants. Control techniques for process emissions are discussed in Section 3.1. Equipment leak control techniques are described in Section 3.2.

3.1 CONTROL TECHNIQUES FOR PROCESS EMISSIONS

Process emissions from chemical processing plants are diverse in composition, flow rate, VOC concentration, temperature, heating value, and miscibility. These factors are extremely important in the selection and design of VOC emission control equipment. Due to this diversity, different control techniques may be appropriate for different vent streams. Process emission control techniques may be characterized by two broad categories: combustion techniques and recovery techniques. Combustion techniques such as flares and incinerators are applicable to a variety of VOC streams. However, combustion of halogenated hydrocarbons (e.g., carbon tetrachloride emissions at the Velsicol plant) may lead to corrosion problems or release of hazardous combustion products (e.g., chlorine gas). Recovery techniques such as condensation, absorption and adsorption, are effective for some select vent streams. Economic incentives may encourage the use of either type of VOC control, since certain combustion configurations may permit heat recovery, and recovery techniques permit the conservation and reuse of valuable materials. The selection of a control system for a particular application is based primarily on considerations of technical feasibility, safety, and process economics.

The most common control techniques form the basis for this chapter. Basic design considerations for flares, thermal and catalytic

incinerators, industrial boilers, condensers, absorbers, and adsorbers, are briefly described. The conditions affecting the VOC removal efficiency of each type of device and its applicability for use in chemical processing plants are examined. Emphasis has been given to flares, thermal incinerators, and condensers because of their wide applicability to a variety of VOC streams. Combustion techniques are discussed in Subsection 3.1.1 and recovery techniques in Subsection 3.1.2.

3.1.1 Control by Combustion Techniques

The four major combustion devices that can be used to control VOC emissions from chemical processing plants are: flares, thermal or catalytic incinerators, and boilers. Flares are a widely used control device at chemical processing plants. Incinerators and boilers are also used, to a lesser extent, to control continuous vent streams. Although these control devices are founded upon basic combustion principles, their operating characteristics are very different. While flares can handle both continuous and intermittent streams, neither boilers nor incinerators can effectively handle large volume intermittent streams.

Combustion is a rapid oxidation process, exothermic in nature, which results in the destruction of VOC by converting it to carbon dioxide and water. Poor or incomplete combustion results in the production of other organic compounds including carbon monoxide. The chemical reaction sequence which takes place in the destruction of VOC by combustion is a complicated process. It involves a series of reactions that produce free radicals, partial oxidation products, and final combustion products. Several intermediate products may be created before the oxidation process is completed. However, most of the intermediate products have a very short life and, for engineering purposes, complete destruction of the VOC is the principal concern.[1]

Destruction efficiency is a function of temperature, turbulence, and residence time. Chemicals vary in the magnitudes of these parameters that they require for complete combustion. An effective combustion technique must provide[2]:

1. Intimate mixing of combustible material (VOC) and the oxidizer (air),
2. Sufficient temperature to ignite the VOC/air mixture and complete its combustion,
3. Required residence time for combustion to be completed, and
4. Admission of sufficient air (more than the stoichiometric amount) to oxidize the VOC completely.

3.1.1.1 Flares. Flaring is an open combustion process in which the oxygen required for combustion is provided by the air around the flame. Good combustion in a flare is governed by flame temperature, residence time of components in the combustion zone, turbulent mixing of components to complete the oxidation reaction, and oxygen for free radical formation.

There are two types of flares: ground level flares and elevated flares. Kalcevic (1980) presents a detailed discussion of different types of flares, flare design and operating considerations, and a method for estimating capital and operating costs for flares.[3] Elevated flares are common in the petroleum refining and chemical industries. The basic elements of an elevated flare system are shown in Figures 3-1 and 3-2. Process offgases are sent to the flare through the collection header. The offgases entering the header can vary widely in volumetric flowrate, moisture content, VOC concentration, and heat value. The knock-out drum removes water or hydrocarbon droplets that could create problems in the flare combustion zone. Offgases are usually passed through a water seal before going to the flare. This prevents a possible flame flashback, caused when the offgas flow to the flare is too low and the flame front moves down into the stack.

Purge gas (N_2, CO_2, or natural gas) also helps to prevent flashback in the flare stack caused by low offgas flow. The total volumetric flow to the flame must be carefully controlled to prevent low flow flashback problems and to avoid a detached flame (a space between the stack and flame with incomplete combustion) caused by an excessively high flow rate. A gas barrier or a stack seal is sometimes used just below the flare head to impede the flow of air into the flare gas network.

The VOC stream enters at the base of the flame where it is heated by already burning fuel and pilot burners at the flare tip. Fuel flows

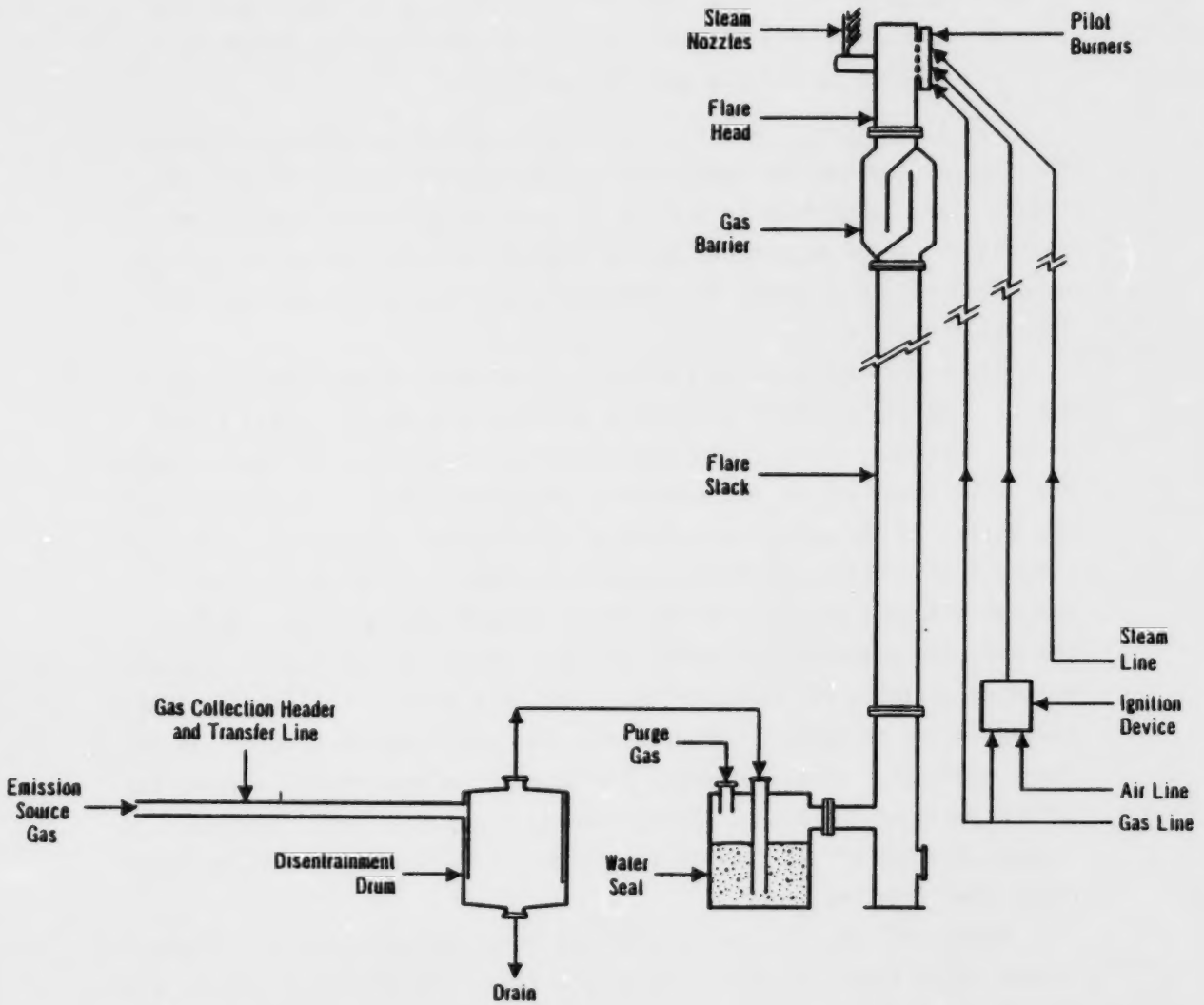

Figure 3-1. Steam Assisted Elevated Flare System.

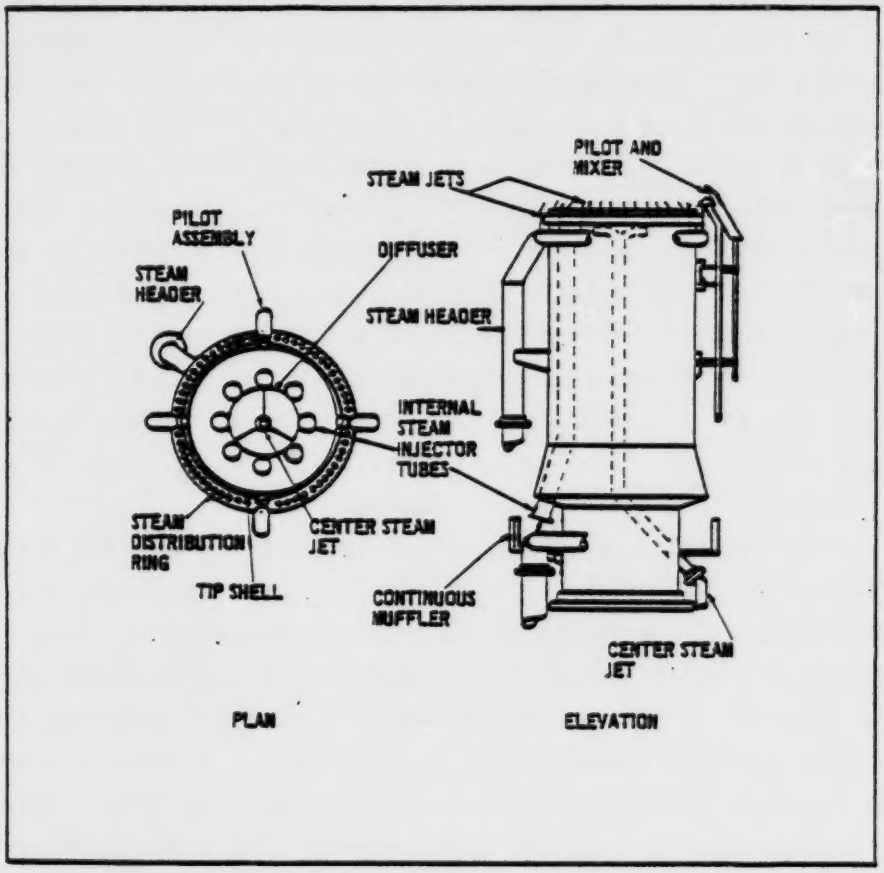

Figure 3-2. Steam Injection Flare Tip.

into the combustion zone where the exterior of the microscopic gas pockets is oxidized. The rate of reaction is limited by the mixing of the fuel and oxygen from the air. If the gas pocket has sufficient oxygen and residence time in the flame zone it can be completely burned. The diffusion flame receives its combustion oxygen by diffusion of air into the flame from the surrounding atmosphere. The high volume of fuel flow in a flare requires more combustion air at a faster rate than into the flame from the surrounding atmosphere. The high volume of fuel flow in a flare requires more combustion air at a faster rate than simple gas diffusion can supply, so flare designers add steam injection nozzles to increase gas turbulence in the flame boundary zones, drawing in more combustion air and improving combustion efficiency. The steam injection promotes smokeless flare operation by minimizing the cracking reactions that form carbon. Significant disadvantages of steam usage are the increased noise and cost. The steam requirement depends on the composition of the gas flared, the steam velocity from the injection nozzle, and the tip diameter. Although some gases can be flared smokelessly without any steam, typically 0.15 to 0.5 kg of steam per kg of hydrocarbon in the flare gas is required.

Steam injection is usually controlled manually with the operator observing the flare (either directly or on a television monitor) and adding steam as required to maintain smokeless operation. Several flare manufacturers offer devices which sense flare flame characteristics and adjust the steam flow rate automatically to maintain smokeless operation.

Some elevated flares use forced air instead of steam to provide the combustion air and mixing required for smokeless operation. These flares consist of two coaxial flow channels. The combustible gases flow in the center channel and the combustion air (provided by a fan in the bottom of the flare stack) flows in the annulus. The principal advantage of air assisted flares is that expensive steam is not required. Air assist is rarely used on large flares because air flow is difficult to control when the gas flow is intermittent. About 600 J/sec (0.8 hp) of blower capacity is required for each 45 kg/hr (100 lb/hr) of gas flared (Klett and Galeski, 1976).[4]

Ground flares are usually enclosed and have multiple burner heads that are staged to operate based on the quantity of gas released to the

flare. The energy of the gas itself (because of the high nozzle pressure drop) is usually adequate to provide the mixing necessary for smokeless operation and air or steam assist is not required. The fence or other enclosure reduces noise and light from the flare and provides some wind protection.

Ground flares are less numerous and have less capacity than elevated flares. Typically they are used to burn gas "continuously" while steam assisted elevated flares are used to dispose of large amounts of gas released in emergencies (Payne, 1982).[5]

After consideration of the results of several tests, EPA has determined that 98 percent combustion efficiency can be achieved by steam assisted and non-assisted flares that are designed and operated with any exit velocity less than 122 meters per second (400 ft/sec) if the net heating value of the gas being combusted is greater than 37.3 megajoules per standard cubic meter (1000 Btu/scf).[6,7]

3.1.1.2 Thermal Incinerators. The design and operation of thermal incinerators are influenced by operating temperature, residence time, desired VOC destruction efficiency, offgas characteristics, and combustion air. Operating temperatures may typically be between 650°C (1,200°F) and 980°C (1,800°F) with a residence time of 0.3 to 1.0 second.[8] The temperature theoretically required to achieve complete oxidation depends on the nature of the chemical involved and can be determined from kinetic rate studies.[8] The design of the combustion chamber should maximize the mixing of the VOC stream, combustion air, and hot combustion products from the burner. This helps ensure that the VOC contacts sufficient oxygen while at combustion temperature, for maximum combustion efficiency.

The heating value and water content of the waste gas feed and the excess combustion air delivered to the incinerator also affect incinerator design and operation. Heating value is a measure of the heat produced by the combustion of the VOC in the waste gas. Gases with a heating value less than 1,860 kJ/scm (50 Btu/scf) will not burn and require auxiliary fuel to maintain combustion. Auxiliary fuel requirements can be reduced and sometimes even eliminated by transferring heat from the exhaust gas to the inlet gas. Offgases with a heating value between 1,860 and 3,720 kJ/scm (50 and 100 Btu/scf) can support combustion but require some auxiliary fuel to ensure flame stability (i.e., avoid a

flameout). Theoretically, offgases with a heating value above 3,720 kJ/scm possess enough heat content to not require auxiliary fuel (although practical experience has shown that 5,580 kJ/scm (150 Btu/scf) and above may be necessary,[9] and these gases may be used as a fuel gas or boiler feed gas.[10] A thermal incinerator handling offgas streams with varying heating values and moisture content requires periodic adjustment to maintain the proper chamber temperatures and operating efficiency. Increases in heat content reduce auxiliary fuel requirements, whereas increases in water content can substantially increase fuel requirements.

Incinerators are always operated with excess air to ensure a sufficient supply of oxygen. The amount of excess air used varies with the fuel and burner type but should be kept as low as possible. Using too much excess air wastes fuel because this air must be raised to the combustion temperature but does not contribute any heat by participating in the oxidation reaction. Large amounts of excess air also increase the flue gas volume and may cause an operator to invest in a larger system than required.

A thermal incinerator usually contains a refractory-lined chamber (which may vary in cross-sectional size along its length) containing a burner at one end. Because of the risk to the refractory, incinerators are neither brought quickly up to nor cooled down quickly from normal operating temperatures. They require a fairly constant fuel input to maintain combustion temperature. A diagram of a thermal incinerator using discrete burners is shown in Figure 3-3. (Numbers in parentheses following the mention of equipment parts or streams denote the numbered items on the referenced figures.) Discrete dual fuel burners (1) and inlets for the offgas (2) and combustion air (3) are arranged in a premixing chamber (4) to thoroughly mix the hot products from the burners with the offgas air streams. The mixture of hot reacting gases then passes into the main combustion chamber (5). This section is sized to allow the mixture enough time at the elevated temperature for the oxidation reaction to be completed (residence times of 0.3 to 1 second are common). Energy can then be recovered from the hot flue gases with the installation of a heat recovery section (6). Preheating of combustion air or the process waste offgas fed to the incinerator by the incinerator exhaust gases will reduce auxiliary fuel usage. In some instances, the incinerator exhaust gas may be used in a waste heat

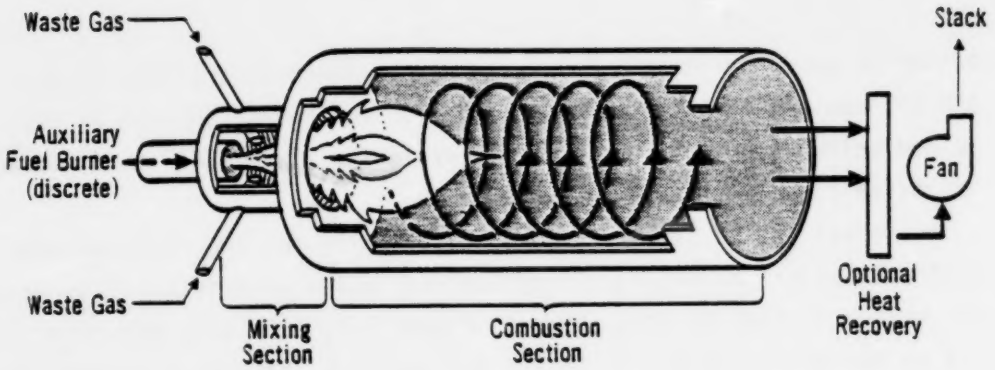

Figure 3-3. Discrete Burner Thermal Incinerator.

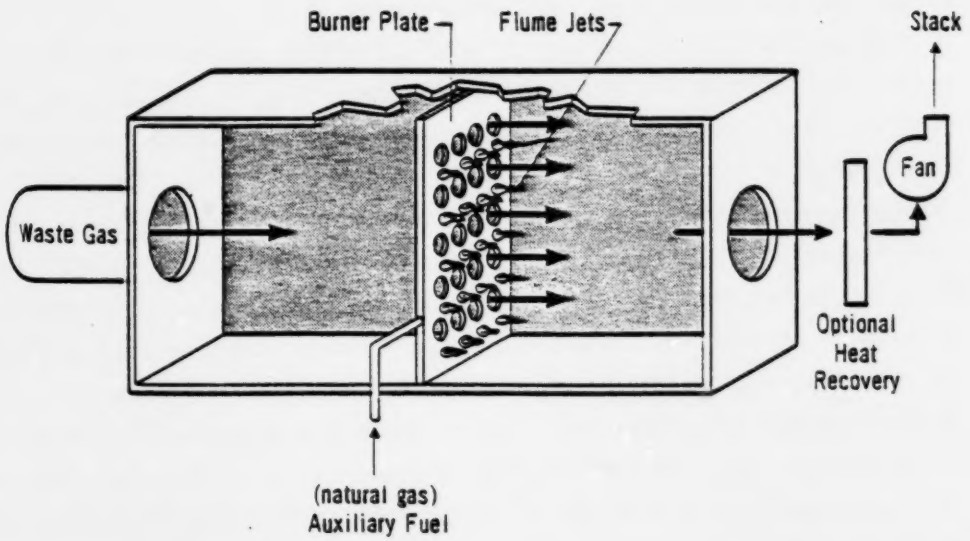

Figure 3-4. Distributed Burner Thermal Incinerator.

boiler to generate steam. Insurance regulations require that if the process waste offgas is preheated, the VOC concentration must be maintained below 25 percent of the lower explosive limit (LEL) to minimize explosive hazards.[11]

Thermal incinerators designed specifically for VOC incineration with natural gas as the auxiliary fuel may use a grid-type (distributed) gas burner similar to that shown in Figure 3-4. The tiny gas flame jets (1) on the grid surface (2) ignite the vapors as they pass through the grid. The grid acts as a baffle for mixing the gases entering the chamber (3). This arrangement ensures burning of all vapors using less fuel and a shorter burning length in the duct than conventional forward flame burners. Overall, this system makes possible a shorter reaction chamber while maintaining high efficiency.[12]

Thermal incinerators used to burn halogenated VOC's often use additional equipment to remove the corrosive combustion products. The flue gases are quenched to lower their temperature and routed through absorption equipment such as spray towers or liquid jet scrubbers to remove the corrosive gases from the exhaust.[11]

The destruction efficiency of an incinerator can be affected by variations in chamber temperature, residence time, inlet concentration, compound type, and flow regime (mixing). Of these, chamber temperature, residence time, and flow regime are the most important. When the temperature exceeds 700°C (1,290°F), the oxidation reaction rate is much faster than the rate at which mixing can take place, so VOC destruction becomes more dependent upon the fluid mechanics within the combustion chamber.[13] Variations in inlet concentration also affect the VOC destruction efficiency achievable; kinetics calculations describing the combustion reaction mechanisms indicate much slower reaction rates at very low compound concentrations. Therefore, at low VOC concentration, a greater residence time is required to achieve a high combustion efficiency.

Test results show that a VOC control efficiency of 98 percent can be achieved consistently for many VOC compounds by well-designed units and can be met under a variety of operating conditions: combustion chamber temperatures ranging from 700 to 1,300°C (1,300 to 2,370°F) and residence times of 0.5 to 1.5 seconds.[14,15]

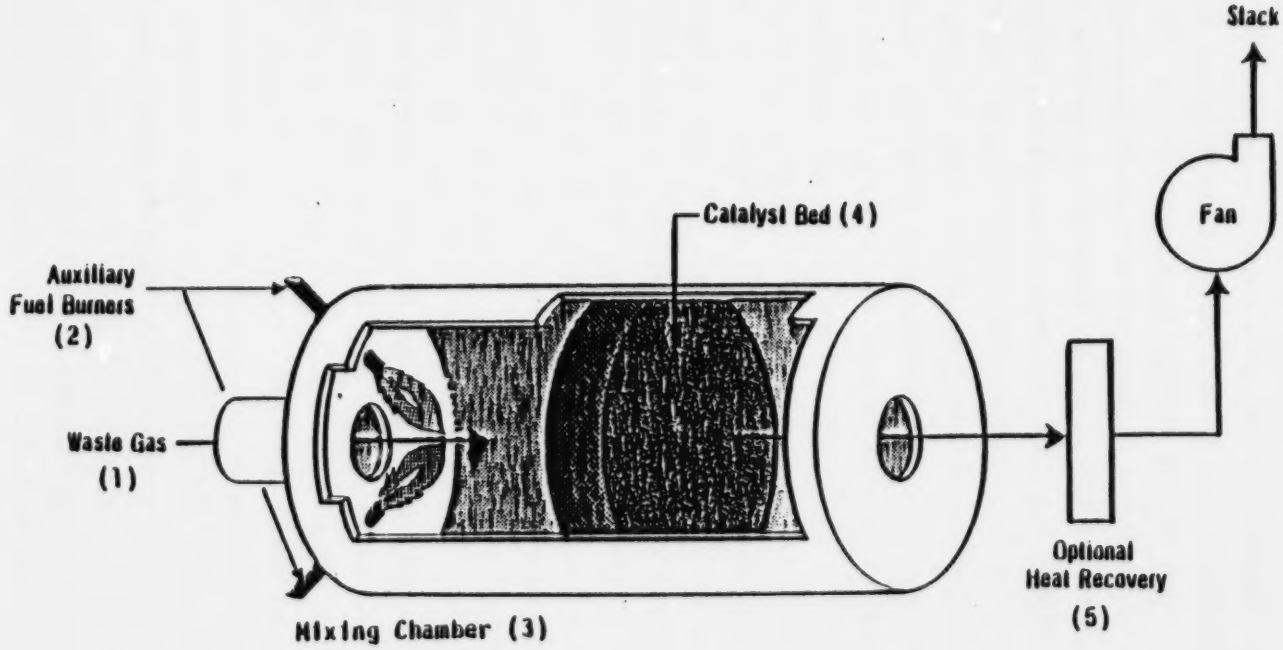

Figure 3-5. Catalytic Incinerator.

3.1.1.3 Catalytic Incinerators. For dilute streams, a catalytic incinerator might be a favorable choice over a thermal incinerator if supplemental fuel requirements are of principal concern. The control principles and equipment used in catalytic incineration are similar to those employed in conventional thermal incineration. The VOC-containing waste gas stream is heated to an appropriate reaction temperature and then oxidation is carried out at active sites on the surface of a solid catalyst. The catalyst increases the rate of oxidation, allowing the reaction to occur at a lower temperature than in thermal incineration. This technique may offer advantages over thermal incineration in auxiliary fuel savings where low VOC content makes large fuel usage necessary. Catalytic incinerators also may produce less NO_x because of lower combustion temperatures and smaller excess air requirements.

Combustion catalysts are made by depositing platinum or platinum alloys, copper oxide, chromium, or cobalt on an inert substrate, which is suitably shaped to fit the mechanical design of the incinerator. The operating temperature of the catalyst is usually from 315°C (600°F) to 650°C (1,200°F). Combustion may not occur below 315°C and temperatures higher than 650°C may shorten the catalyst life or even evaporate catalyst from the support substrate.[16] Accumulation of particulate matter, condensed VOC's, or polymerized hydrocarbons on the catalyst can block the active sites and reduce its effectiveness. Catalysts can also be contaminated and deactivated by compounds containing sulphur, bismuth, phosphorous, arsenic, antimony, mercury, lead, zinc, tin, or halogens. If the catalyst is so "poisoned," VOC's will pass through unreacted or only partially oxidized. Catalytic incinerators can operate efficiently treating offgas streams with VOC concentrations below the lower explosive limit. This is a distinct advantage over thermal incinerators which would in this situation require auxiliary fuel.

A schematic of a catalytic incinerator unit is shown in Figure 3-5. During operation, the waste gases (1) first enter the mixing chamber (also called the preheat zone) (2) where they are heated by contact with the hot combustion products of a burner (3). The mixing chamber temperature may vary as a function of the composition and type of contaminants to be oxidized, but will generally operate in the range of

343°C (650°F) to 593°C (1,100°F).[17] The heated mixture then passes through the catalyst bed (4) where oxygen and VOC's diffuse to the 40talyst and are adsorbed on its surface. The oxidation reaction takes place at these "active sites." Reaction products desorb from the active sites and diffuse back into the waste gas. As with the exhaust gases from thermal incinerators, the products of combustion leaving the bed may be used in a waste heat recovery device (5) before being exhausted to the atmosphere.

The destruction efficiency of catalytic incinerators is a function of many variables, including type of catalyst, its surface area, volume, and pore size distribution, gas composition, uniformity of flow through the catalyst bed, oxygen concentration, and temperature in the unit.[16,17] The efficiency of a catalytic incinerator will deteriorate over time, necessitating periodic replacement of the catalyst. The replacement time varies widely, depending on the service of the unit, from less than 1 year up to 10 years,[8] with an average life between 3 and 5 years.[18]

A 1980 study by Engelhard Industries for the EPA involved testing of both pilot and full-scale catalytic incineration systems. The full-scale unit installed on a formaldehyde plant achieved control efficiencies ranging from 97.9 to 98.5 percent. These efficiencies represent overall control levels for carbon monoxide, methanol, dimethyl ether, and formaldehyde.[19]

3.1.1.4 Industrial Boilers. Fireboxes of boilers and process heat can be used, under proper conditions, to incinerate waste streams that contain VOC's. Combustible contaminants, including smoke, organic vapors, and gases can be converted essentially to carbon dioxide and water in boiler fireboxes. As the primary purpose of the boiler is to generate steam, all aspects of operation must be thoroughly evaluated before this method of air pollution control can be used. Any breakdown in the boiler can result in expensive process downtime. Consequently, the risk of shutdown should be kept small and only streams that do not threaten boiler performance should be introduced.

For the satisfactory use of boilers as a control device, there are several prerequisites. Generally, the burner must be modified (e.g., to achieve proper flame luminosity), the boiler must operate continuously and concurrently with the pollution source, the contaminants must be

completely combustible, and the products of combustion must not corrode the materials used to construct the boiler. Corrosive VOC compounds can be combusted in a boiler, but special attention must be given to operate above the dew point of the corrosive material. If these gases are allowed to condense, severe corrosion problems will occur. Further, the volumetric flow rate of low VOC concentration emission streams must be taken into consideration because they can reduce thermal efficiencies in the same way as excess combustion air does. The pressure drop caused by additional products of combustion should not exceed the draft provided by boiler auxiliaries. Boiler life, efficiency, and capacity can be affected by the presence of contaminants in the VOC emission streams. Halogens, for example, would be devastating to the life of boiler tubes. Finally, a personnel safety hazard may occur if coal-fired boilers that are not pulverized coal-fired are used to destroy organic waste. Any interruption in the air supply to these types of boilers would release into the boiler house combustion vapors and any hazardous or toxic substances that may have been injected.[20] Great care, therefore, must be exercised in selecting this mode of pollution control.

The large majority of industrial boilers are of water tube design. Water, circulated through the tubes, absorbs the heat of combustion. Drums store the superheated water from which steam is directed to external heat exchangers for use as process steam.

Both forced and natural draft burners, designed to thoroughly mix the incoming fuel and combustion air, may be used. After ignition, the mixture of hot reacting gases passes through the furnace section that is sized to allow the oxidation reaction to reach completion and to minimize abrasion on the banks of the water tubes. Energy transfer from the hot flue gases to form steam can attain greater than 85 percent efficiency.[23] Additional energy can be recovered from the hot exhaust gases by installation of a gas-gas heat exchanger to preheat combustion air.

Boilers designed specifically for use as a VOC control device typically use discrete or vortex burners, depending on the heating value of the vent stream. A high intensity or vortex burner can be effective for vent streams with low heating values (i.e., streams where

a conventional burner may not be applicable). Effective combustion of low heating value streams is accomplished in a high intensity burner by passing the combustion air through a series of spin vanes to generate a strong vortex.

A boiler would be used as a control device only if the process generated its own steam or the fuel value of the waste gas was sufficient to make the process a net exporter of steam. Whenever either condition exists, installation of a boiler is an excellent control measure that provides very efficient recovery of the heat of combustion of the waste gas. The efficiency of boilers as a VOC control device generally increases with (1) operating temperature, (2) flame contact, and (3) residence time. Properly operated boilers can achieve VOC control efficiencies in excess of 95 percent.[16]

3.1.2 Control by Recovery Techniques

The three major recovery devices are condensers, adsorbers, and absorbers. These devices permit many organic materials to be recovered and, in some cases, reused in the process. Recovery techniques either condense the organic or contact the VOC-containing gas stream with an appropriate liquid or solid. Gases containing only one or two organic gases are easier to process by recovery techniques than multi-component mixtures. The presence of inert or immiscible components in the waste gas mixture complicates recovery techniques. Condensers can be used in series with other air pollution control devices. A condenser located upstream of an incinerator, adsorber, or absorber will reduce the VOC load entering a downstream control device. Adsorbers are used on gas streams that contain relatively low VOC concentrations (concentrations usually well below the lower explosive limit). Carbon adsorbers serve to contain and concentrate dilute organic vapors. When the vapors are in a concentrated form they are either recovered or disposed of. Gas absorption as an emission control method is currently most widely used for the removal of water-soluble inorganic contaminants (e.g., sulfur dioxide, hydrogen sulfide, hydrogen chloride, and ammonia) from air streams, with water being the most common solvent or scrubbing fluid used. Water may also be used for the absorption of organic compounds that have relatively high water solubilities (e.g., most alcohols, organic acids, aldehydes, ketones, amines, and glycols). For

organic compounds that have low water solubilities, other solvents (usually organic liquids with low vapor pressures) are used.[26]

3.1.2.1 Condensers. Condensation devices transfer thermal energy from a hot vapor to a cooling medium, causing the vapor to condense. Condenser design thus typically requires knowledge of both heat and mass transfer processes. Heat may be transferred by a combination of three modes: conduction, convection, or radiation.

The design of a condenser is significantly affected by the number and nature of components present in the vapor stream. The entering gases may consist of a single condensable component or any number of gaseous components which may or may not all be condensable or miscible with one another. At a fixed pressure, a pure component will condense isothermally at the saturation or equilibrium temperature, yielding a pure liquid condensate. A vapor mixture, however, does not have a single condensate temperature. As the temperature drops, condensation progresses, and the composition, temperature, enthalpy, and flow rate of both the remaining vapor and the condensate will change. These changes can be calculated from thermodynamics data, if it is assumed that the vapor and liquid condensate are in equilibrium. Variations in composition and temperature will affect most of the physical and transport properties which must be used in condenser design calculations. When these properties change, the calculations governing the heat transfer process are adjusted to accommodate these changes.

In a two-component vapor stream with one noncondensable component, condensation occurs when the partial pressure of the condensable component is equal to the component's vapor pressure. To separate the condensate from the gas at fixed pressure, the temperature of the vapor mixture must be reduced. The liquid will begin to appear when the vapor pressure of the condensable component becomes equal to its partial pressure, the "dew point." Condensation continues as the temperature is further reduced. The presence of a noncondensable component interferes with the condensation process, because a layer of noncondensable on the condensate acts as a heat transfer barrier.

Two types of condensers are employed: contact and surface. Contact, or direct, condensers cause the hot gas to mingle intimately with the cooling medium. Contact condensers usually operate by spraying

a cool liquid directly into the gas stream. Contact condensers also may behave as scrubbers since they sometimes collect noncondensable vapors which are immiscible with the coolant. The direct contact between the vapor and the coolant limits the application of contact condensers since the spent coolant can present a secondary emission source or a wastewater treatment problem,[21] unless it is economically feasible to separate the two in a subsequent process.

Surface, or indirect, condensers are usually common shell-and-tube heat exchangers. The coolant usually flows through the tubes and the vapor condenses on the outside of the tubes. In some cases, however, it may be preferable to condense the vapor inside the tubes. The condensate forms a film on the cool tube and drains to storage.[16] The shell-and-tube condenser is the optimum configuration from the standpoint of mechanical integrity, range of allowable design pressures and temperatures, and versatility in type of service. VOC removal efficiency of a condenser is dependent upon the composition of the stream. Single component streams with a relatively high boiling point will easily condense, resulting in essentially 100 percent control efficiency. Shell-and-tube condensers may be designed to safely handle pressures ranging from full vacuum to approximately 41.5 MPa (6,000 psig), and for temperatures in the cryogenic range up to approximately 1,100°C (2,000°F).[22] Surface condensers usually require more auxiliary equipment for operation (such as a cooling tower or a refrigeration system) but offer the advantage of recovering valuable VOC without contaminating the coolant, thereby minimizing waste disposal problems. The successively more volatile material returned from the condenser to the distillation column is termed "reflux," or overhead product. The heavier compounds removed at the bottom are often called column "bottoms."[23]

The major pieces of equipment used in a typical refrigerated surface condenser system are shown in Figure 3-6.[21] Refrigeration is often required to reduce the gas phase temperature sufficiently to achieve low outlet VOC concentrations. This type of system includes dehumidification equipment (1), a shell-and-tube heat exchanger (2), a refrigeration unit (3), recovery tank (4), and operating pumps (5). Heat transfer within a shell-and-tube condenser occurs through several

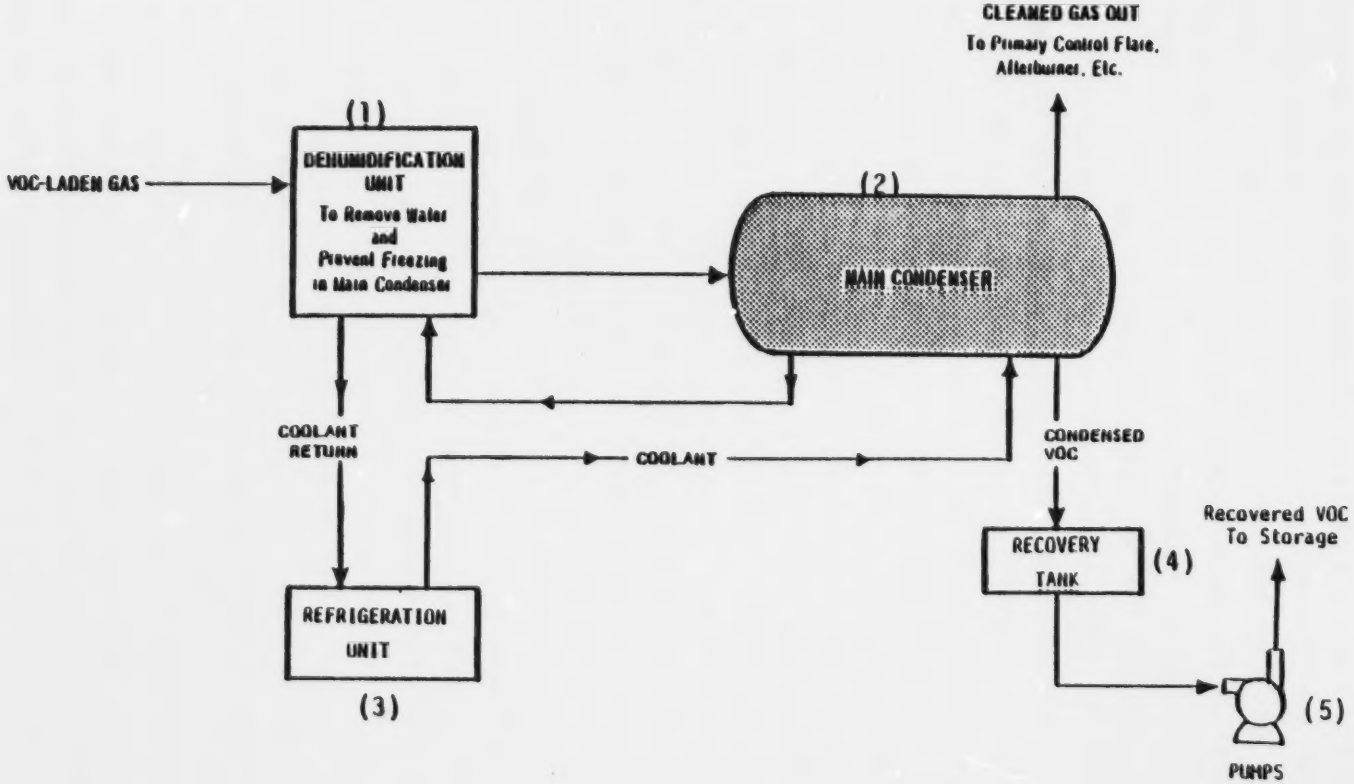

Figure 3-6. Condensation System.

material layers, including the condensate film, combined dirt and scale, the tube wall, and the coolant film. The choice of coolant used depends on the saturation temperature of the VOC stream. Chilled water can be used to cool down to 4°C (40°F), brines to -34°C (-30°F), and chlorofluorocarbons below -34°C (-30°F). Temperatures as low as -62°C (-80°F) may be necessary to condense some VOC streams.[21] VOC removal efficiency of a condenser is dependent upon the composition of the stream. Single component streams with a relatively high boiling point will easily condense, resulting in essentially 100 percent control efficiency.

3.1.2.2 Adsorbers. Vapor-phase adsorption utilizes the ability of certain solids to preferentially adsorb and thereby concentrate certain components from a gaseous mixture onto their surfaces. The gas phase (adsorbate) is pumped through a packed bed of the solid phase (adsorbent) where selective components are captured on its surface by physical adsorption. The organic molecules are retained at the surface of the adsorbent by means of intermolecular or Van-der-Waals forces. The adsorbed organics can be removed and the adsorbent regenerated.

The most common industrial vapor-phase adsorption systems use beds of activated carbon. Carbons made from a variety of natural materials (wood, coal, nut shells, etc.) are marketed for their special adsorbent properties. The multiple bed system maintains at least one bed online while another is being regenerated. Most systems direct the vapor stream downward through a fixed carbon bed. Granular carbon is usually favored because it is not easily entrained in the exhaust stream.

Figure 3-7 is a schematic of a typical fixed bed, regenerative carbon adsorption system. The process offgases are filtered and cooled (1) to minimize bed contamination and maximize adsorption efficiency. The offgas is directed through the porous activated carbon bed (2) where adsorption of the organics progresses until the activated carbon bed is "saturated". When the bed is completely saturated, the organic will "breakthrough" the bed with the exhaust gas and the inlet gases must then be routed to an alternate bed. The saturated bed is then regenerated to remove the adsorbed material.

Low-pressure steam (3) is usually used to heat the carbon bed during the regeneration cycle, driving off the adsorbed organics, which

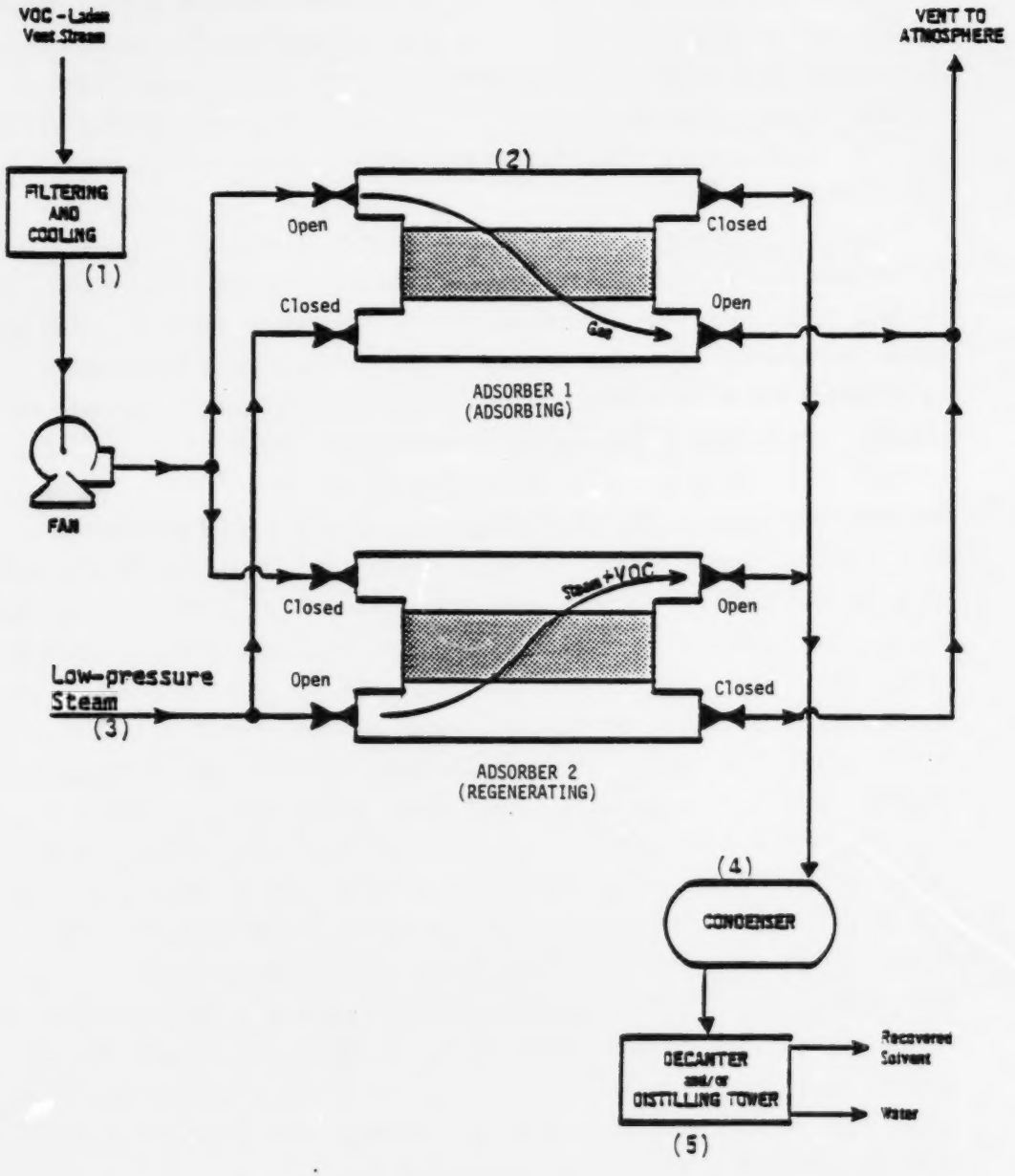

Figure 3-7. Two Stage Regenerative Adsorption System

are usually recovered by condensing the vapors (4) and separating them from the steam condensate by decanting or distillation (5). The adsorption/regeneration cycle can be repeated numerous times, but eventually the carbon loses its adsorption activity and must be replaced. Typically, facilities replace a portion of the carbon bed on an annual basis. The carbon in the bed is vibrated on a sieve/screen to remove the fines. The fines are replaced with fresh carbon. The carbon can be reactivated by recharring, also.

The efficiency of an adsorption unit depends on the properties of the carbon and the adsorbate, and on the conditions under which they contact. Lower temperatures aid the adsorption process, while higher temperatures reduce the adsorbent's capacity.[25] Removal efficiencies of 95 to 99 percent are achieved by well-designed and well-operated units.[26]

3.1.2.3 Absorbers. Absorption is a gas-liquid mass transfer operation in which a gas mixture is contacted with a liquid (solvent) for the purpose of preferentially dissolving one or more components (solutes) of the gas. Absorption may entail only the physical phenomenon of solution or may also involve chemical reaction of the solute with constituents of the solvent.[2]

For any given solvent, solute, and set of operating conditions, there exists a theoretical equilibrium ratio of solute concentration in the gas mixture to solute concentration in the solvent. The driving force for mass transfer in an operating absorption tower is related to the difference between the actual concentration ratio and this equilibrium ratio.[26] The solvents used are chosen for high solute (VOC) solubility and include liquids such as water, mineral oil, nonvolatile hydrocarbon oils, and aqueous solutions of oxidizing agents like sodium carbonate and sodium hydroxide.[16]

Devices based on absorption principles include spray towers, venturi scrubbers, packed columns, and plate columns. Spray towers and venturi scrubbers are generally restricted to particulate removal and control of high-solubility gases.[26] Most VOC control by gas absorption is by packed or plate columns. Packed columns are used mostly for handling corrosive materials, liquids with foaming or plugging tendencies, or where excessive pressure drops would result from the use of

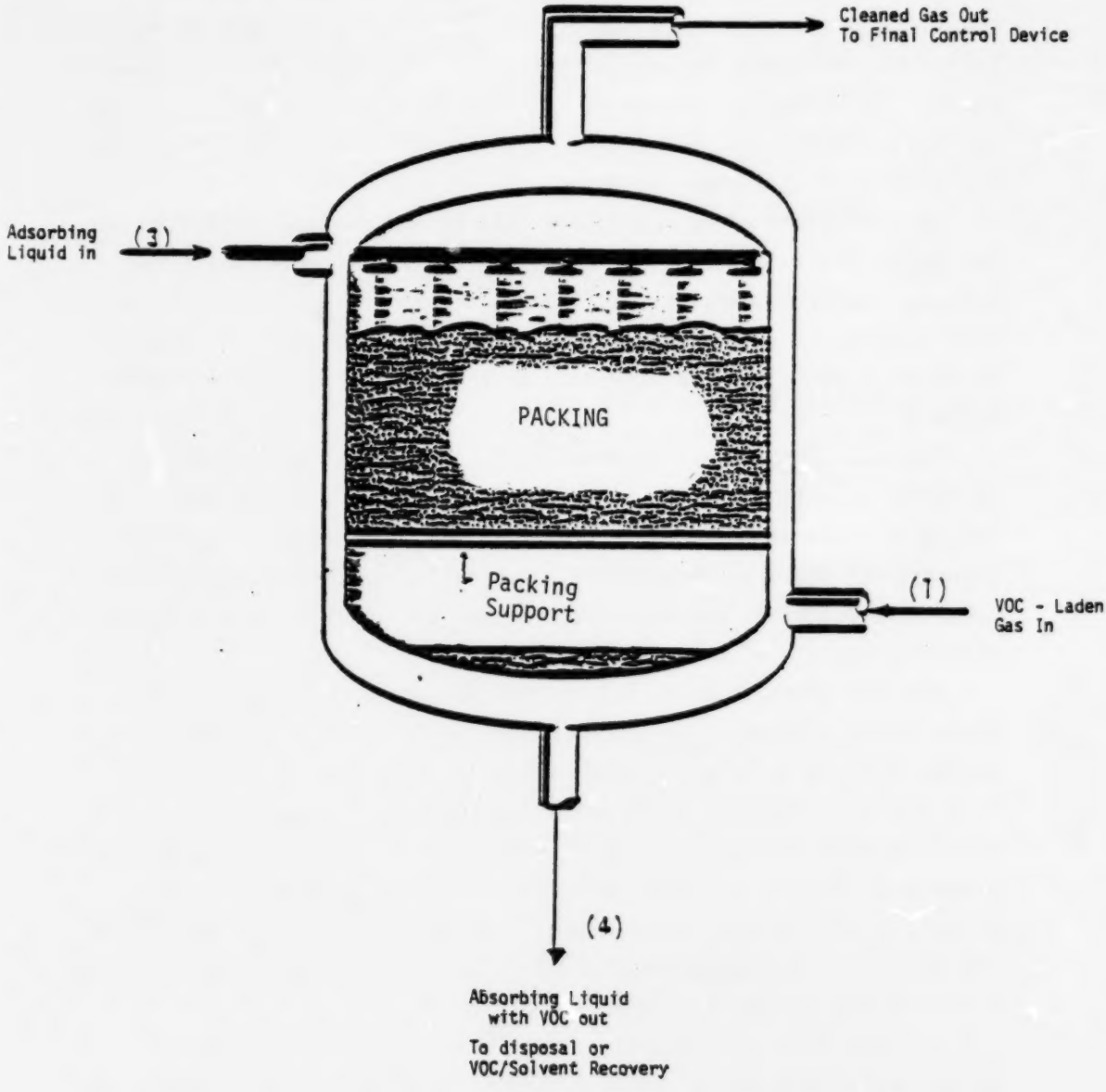

Figure 3-8. Packed Tower for Gas Absorption

plate columns. They are less expensive than plate columns for small-scale or pilot plant operations where the column diameter is less than 0.6 m (2 ft). Plate columns are preferred for large-scale operations, where internal cooling is desired, or where low liquid flowrates would inadequately wet the packing.[16]

A schematic of a packed tower is shown in Figure 3-8. The gas is introduced at the bottom (1) and rises through the packing material (2). Solvent flows by gravity from the top of the column (3), countercurrent to the vapors, absorbing the solute from the gas phase and carrying the dissolved solute out of the tower (4). Cleaned gas exiting at the top is ready for release or final treatment such as incineration.

The VOC control efficiencies of absorption systems are discussed in reference 26. The relationship between VOC removal efficiency and the major tower design parameters (column diameter and height, pressure drop, and liquid flowrate) are based on the specific surface area of the tower packing, the solubility and concentration of the components, and the quantity of gases to be treated.

3.2 EQUIPMENT LEAK CONTROL TECHNIQUES

This section discusses control techniques that can be applied to reduce VOC emissions from equipment components from chemical processing plants. Two approaches are available. The first approach presented in Subsection 3.2.1 involves implementing a leak detection and repair program in which components are inspected at specified intervals to detect leakers for repair. A second preventive approach is presented in Subsection 3.2.2 whereby potential emissions are vented to a control device or eliminated through specified controls or installation of leakless equipment.

3.2.1 Leak Detection and Repair Programs

Leaking equipment can be detected in several ways. Predominant industry practice is detection by visual, audible, and olfactory methods, a unit area survey, or by means of a fixed point monitoring system. However, in many instances, even very large VOC leaks are not detected by these methods.

Another leak detection method is to apply a soap solution (soaping) to equipment components. If bubbles form in the soap solution, a potential leak is indicated. Soaping may serve as a preliminary

screening technique, in that the number of equipment components otherwise subject to instrument monitoring may be reduced to only those components for which bubbles were detected. Soaping is not appropriate for very hot sources, although ethylene glycol can be added to the soap solution to extend the temperature range. This method is also not suited for moving shafts on pumps or compressors, since the motion of the shaft may cause entrainment of air in the soap solution and indicate a leak when none is present. In addition, the method cannot generally be applied to open sources such as relief valves or vents without additional equipment.

The use of portable hydrocarbon detection instruments is the best method for identifying leaks of VOC from equipment components because it is applicable to all types of sources. EPA Reference Method 21, "Determination of Volatile Organic Compound Leaks," specifies the procedures for instrument monitoring. This method incorporates the use of a portable analyzer to detect the presence of volatile organic vapors at the surface of the interface where direct leakage to atmosphere could occur. A measure of the hydrocarbon concentration of the sampled air is displayed in the instrument meter. The approach of this technique assumes that if an organic leak exists, there will be an increased vapor concentration in the vicinity of the leak, and that the measured vapor concentration is generally proportional to the mass emission rate of the organic compound.

When a leak is located, the leaking component can be scheduled for repair or replacement. Many components can be serviced on-line without disturbing the plant operations. An example would be the tightening of a valve packing gland. If tightening the packing gland does not stop the leak, the valve must be isolated from the process before repair can be attempted. Control valves can often be isolated, but block valves generally cannot be.

Repairs of rotary equipment seals usually require isolation of the leaking device. Almost all process pumps are "spared" (two installed in parallel, but only one required for operation) so that either one can be isolated for repair. However, most compressors are not spared, and so compressor seal replacements often necessitate a partial or complete shutdown.

Most leaking flanges can be resealed simply by retightening the flange bolts. A flange leak that requires a gasket seal replacement may require a total or partial shutdown of the entire unit. When the leaks can be corrected only by a total or partial shutdown, the temporary emissions resulting from a shutdown and startup could be larger than the continuous fugitive emissions that would take place before a scheduled shutdown. For this reason, the repajr of certain leaks is best delayed until the next scheduled shutdown.

The emission reduction achieved by a leak detection and repair program is dependent on several factors, including the leak definition, the inspection interval, the allowable delay until repair, and the effectiveness of the repair. To implement a monitoring program, an instrument meter reading (organics concentration) which will indicate an equipment leak must be defined. The meter reading selected may vary from 1,000 ppmv to 100,000 ppmv. The theoretical efficiency can then be estimated by relating the leak definition to the percentage of total mass emissions that can be expected from sources with concentrations at the source greater than the leak definition. In general, defining a leak by a low meter reading results in larger potential emission reductions. However, the potential increase in emissions that can occur through attempts at repairing relatively minor leaks may dictate that these leaks be excluded from the leak definition. The inspection interval depends on the expected occurrence and recurrence of leaks after a piece of equipment has been checked and/or repaired. This interval can also vary with the type of equipment and service conditions. Monitoring may be scheduled on an annual, quarterly, monthly, or weekly basis. If a leak is detected, the equipment should be repaired as soon as practicable. The longer the delay, the less effective will be the overall reduction program.

Table 3-1 summarizes the effectiveness of a quarterly leak detection and repair program similar to those currently implemented under existing State and local regulations for petroleum refineries and SOCMI plants. A full discussion of leak detection and repair program effectiveness can be found in the control technique guideline document for control of VOC leaks from the synthetic organic chemical and polymer

Table 3-1. EFFECTIVENESS OF QUARTERLY LEAK DETECTION AND REPAIR

Equipment Component/Service	Emission Reduction Effectiveness, Percent[a]	Emission Reduction Per Component, kg/hr[b]	Emission Reduction, Per Model Plant, Mg/yr[c] A	B	C
Pumps					
light liquid	32.5	0.016	1.1	3.3	22
Valves					
gas	63.9	0.0035	3.0	5.2	27
light liquid	43.9	0.0031	3.5	6.1	80
Safety/relief devices					
gas	44.2	0.046	4.4	13.4	40
		TOTAL	12	28	169

[a]Reference 27. p. 3-8.

[b]Example calculation: pumps

$$\begin{pmatrix}\text{Emission Reduction}\\ \text{Effectiveness}\end{pmatrix} \times \begin{pmatrix}\text{Emission Factor,}\\ \text{from Table 2-3}\end{pmatrix} = \begin{pmatrix}\text{Emission Reduction}\\ \text{Per Component}\end{pmatrix}$$

$$(0.325)(0.04994 \text{ kg/hr}) = 0.016 \text{ kg/hr.}$$

[c]Example calculation Model Plant A: pumps

$$\begin{pmatrix}\text{Emission Reduction}\\ \text{per Component, kg/hr}\end{pmatrix} \begin{pmatrix}\text{Components per}\\ \text{model plant,}\\ \text{from Table 2-4}\end{pmatrix} \left(\frac{8{,}600 \text{ hrs/hr}}{1{,}000 \text{ kg/Mg}}\right) = \begin{matrix}\text{Model Plant}\\ \text{Emission}\\ \text{Reduction,}\\ \text{Mg/yr}\end{matrix}$$

$$(0.016 \text{ kg/hr})(8 \text{ pump seals})\left(\frac{8{,}600 \text{ hr/yr}}{1{,}000 \text{ kg/Mg}}\right) = 1.1 \text{ Mg/yr.}$$

manufacturing equipment and an additional information document on equipment leaks issued by the EPA.[27,28]

3.2.2 Preventive Programs

An alternative approach to the leak repair program is to replace the potentially leaky equipment with components based on "leakless" technology, or with equipment that captures the leakage for control. This approach is referred to as a preventive program. For example, in many cases, emissions from a pump seal can be reduced to a negligible level through the installation of an improved shaft sealing mechanism, such as dual mechanical seals, or it can be eliminated entirely by installing sealless pumps, which do not have a shaft/casing junction and thus do not leak during normal operation. A barrier fluid can be circulated between the mechanical seals. Degassing vents in the barrier fluid system allow the transport of leakage in a closed system to a control device. These solutions are sometimes not feasible. For example, the maximum service temperature of a dual mechanical seal is usually about 260°C (500°F). Mechanical seals also cannot be used on pumps with reciprocating shaft motion or those handling extremely corrosive or abrasive fluids.

Leakage from safety/relief devices can be minimized by installing a rupture disk upstream of each device. Such combinations can be spared by installation of a two-way valve which assures that one emergency relief system is always operational. The other could then be repaired while process operations continue. In some applications it may be feasible to vent safety/relief device emissions to a control device such as those presented in Section 3.1.

Caps, plugs, and second valves are devices that can essentially eliminate leakage from open-ended lines. VOC emissions from the purging of sampling lines can be minimized by a closed-purge sampling system that enables purge organics to be recycled to the process or contained for subsequent disposal.

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4.0 ENVIRONMENTAL ANALYSIS OF RACT

This chapter discusses the environmental impacts that would result from implementing reasonably available control technology (RACT), which is presented in Section 4.1. The primary emphasis is a quantitative assessment of VOC emissions in the absence of RACT (baseline emissions) and after implementation of RACT. The impacts of RACT upon water pollution, solid waste, and energy consumption are also addressed in this chapter.

4.1 REASONABLE AVAILABLE CONTROL TECHNOLOGY (RACT)

Reasonably available control technology for chemical processing plants in Shelby County consists of a performance requirement for process vent streams and equipment and work practices for equipment components in VOC service. Control devices should be used to reduce VOC emissions from process vent streams by at least 85 percent. The RACT requirements for process vent streams would apply only to vent streams with a potential VOC emission rate of 5.4 kg/hr (12 lbs/hr) or more. Control costs for vent streams emitting less than 5.4 kg/hr VOC may be unreasonable.

RACT procedures for equipment components include weekly visual inspection of pumps and quarterly monitoring of pumps, valves, and relief devices. Relief devices should be monitored and repaired if necessary after they have vented to the atmosphere. Routine instrument monitoring is not necessary for flanges and connections or other equipment in heavy liquid service. Any component that appears to be leaking on the basis of sight, smell, or sound should be repaired. In addition, difficult-to-monitor valves may require less frequent than quarterly monitoring. Except when the open end is in use (e.g., collecting samples), open-ended lines should be sealed with a second valve, a blind flange, a cap, or a plug. In the case of a second valve, the upstream valve should be closed first after each use.

RACT procedures for equipment components at chemical processing plants with less than 250 valves in VOC service would only consist of monthly inspections of pumps and repair of any equipment component observed leaking, based on sight, smell, or sound.

The organics detection instrument and the monitoring method employed should conform to EPA Reference Method 21 or an equivalent method. A source is considered leaking if monitoring results in an instrument reading of 10,000 ppmv or greater. As discussed in Section 3.2.1, a soap solution may be applied to certain equipment as a preliminary screening technique for leakage. Leaking components should be tagged and repaired within 15 days. In those instances where a leak cannot be repaired within 15 days because of interference with plant operations, the leak should be repaired at the next line shutdown.

RACT should be applicable only to components in VOC service. A component is in VOC service if it contains ten percent or greater VOC by weight. A VOC organic is any compound which participates in atmospheric photochemical reactions. For the purpose of this document, a light liquid is defined as a fluid with a vapor pressure greater then 0.3 K Pa (psi) at 20°C. A component should be considered in light liquid service if it contacts a fluid containing greater than ten percent by weight light liquid. An equipment component is in heavy liquid service if the percent evaporated is less than 10 percent at 150°C as determined by ASTM Method D-86. A component should be considered in gas service if it contains process fluid that is in the gaseous state at operating conditions. RACT does not apply to equipment operating under vacuum.

4.2 AIR POLLUTION

Implementation of RACT would reduce VOC emissions from process vents and from equipment leaks resulting in a significant beneficial impact on air pollution. The emission reduction is the difference between the amount of emissions before RACT is implemented and the amount of emissions after RACT is implemented. Annual emission reductions from the few plants listed in Table 2-2, are estimated at 5,400 Mg (6,000 tons) per year based on 85 percent control of the uncontrolled emission sources greater than 5.4 kg/hr (about 50 tons per year). Reductions of VOC emissions from leaking equipment are presented for the model plants in Table 3-1. Total emission reductions from equipment leaks in Shelby County shown in Table 4-1 are estimated at more than 300 Mg per year.

Table 4-2. ESTIMATED EMISSION REDUCTIONS FROM IMPLEMENTING RACT FOR EQUIPMENT COMPONENTS AT TWO LARGE CHEMICAL PROCESSING PLANTS IN SHELBY COUNTY, TENNESSEE

Equipment Component/Service	Equipment Estimates by Company[a]			Emission Reduction	
	DuPont	Velsicol	Total	Per Component, Kg/yr[b]	Shelby Co. Total Mg/yr[c]
Valves					
gas	929	105	1,034	0.0035	31.1
light liquid	3,032	800	3,832	0.0031	102
Relief Devices					
gas	132	19	151	0.046	59.7
Open Ended Lines-all	1,368	254	1,622	0.0017	23.7
Pumps					
light liquid	166	101	267	0.046	106
				Total	322

[a]From the Memphis-Shelby County VOC Emissions Inventory. Reference 2.

[b]From Table 3-1. Emission reductions for open-ended lines is essentially 100 percent.

[c]Example calculation: Valves in gas service

$$\left(\begin{array}{l}\text{Total estimated}\\ \text{no. of components}\\ \text{in Shelby County}\end{array}\right)\left(\begin{array}{l}\text{Emission reduction}\\ \text{per component,}\\ \text{Kg/hr}\end{array}\right)\left(\frac{8{,}600\ \text{hrs/yr}}{1{,}000\ \text{Kg/Mg}}\right) = \begin{array}{l}\text{Shelby County}\\ \text{total emissions}\end{array}$$

$$(1034)(0.0035)\left(\frac{8{,}600}{1{,}000}\right) = 31.1\ \text{Mg/yr.}$$

4.3 WATER POLLUTION

Implementation of RACT would not significantly impact water quality. Control of process vent streams through adsorption, absorption, or condensation may slightly increase the waste load entering chemical processing plant wastewater treatment systems. The increase in waste-water from these devices would be negligible in comparison to existing discharges from plants. Equipment controls, however, would reduce equipment leaks entering the wastewater systems.

4.4 SOLID WASTE DISPOSAL

In most cases, implementation of RACT on process vent streams will not impact solid waste disposal. However, plants that choose to utilize catalytic incineration and carbon adsorption will have a slight increase in the amount of solid waste disposal. In general, catalyst and carbon beds need to be replaced every 3 to 5 years. Solid wastes generated by leak detection and repair for process equipment include replaced mechanical seals, seal packing and components that are replaced. The additional solid waste generated from RACT controls are not expected to have a significant impact on solid waste.

4.5 ENERGY

The energy impacts from implementing RACT will vary from plant to plant depending upon the types of control techniques chosen to implement RACT. Additional energy consumption would result from process emission control. The increased energy consumption would consist of: natural gas by flares, thermal incinerators, and catalytic incinerators; electricity by thermal incinerators, catalytic incinerators, condensers, adsorbers, and absorbers, and steam by flares and adsorbers. The increase in energy consumption may be offset by the energy-equivalent value of recovered product from use of condensers, absorbers, adsorbers or from the heating value of process streams vented to process heaters or boilers. Implementation of RACT for equipment components will result in energy credits by preventing and reducing the amount of process fluids from leaking equipment.

4.6 REFERENCES

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5.0 CONTROL COST ANALYSIS OF RACT

The costs of implementing reasonably available control technology (RACT) for controlling emissions of VOC from chemical processing plants are presented in this chapter. Capital costs, annualized costs, and the cost effectiveness of RACT are presented. The control cost analysis presented herein examines process vent emission controls in Section 5.1 and equipment leak controls in Section 5.2. All costs presented in this document have been converted to December 1984 dollars using the plant cost indices published in the Chemical Engineering Economic Indicators.

5.1 PROCESS VENT CONTROL COSTS

In the preceding chapter, several control techniques were presented as the basis for implementing RACT for process vent VOC emission sources. Due to the wide variability in process vent streams, the costs for implementing RACT are presented for five model process vent streams.

The model vent streams (I, II, III, IV, and V) are representative of those found in Shelby County, Tennessee, and the control techniques chosen as the basis for cost analysis reflect the range of applicable VOC control methods. The capital cost analysis developed for process vents I, II, and III reflect estimates from discussions with control equipment manufacturers. The annualized cost analysis is estimated from procedures detailed in reference 2. A detailed cost analysis prepared for each model process vent stream is presented in Appendices C through E of this document. A summary of the five model process vent stream characteristics and the control techniques applied as the basis for cost analysis are presented in Table 5-1. The capital costs, annualized costs, and cost effectiveness of the control techniques applied to each model process vent are summarized in Table 5-2.

5.2 EQUIPMENT LEAK CONTROL COSTS

This section presents costs associated with implementing RACT for equipment components. These costs include the costs for installing caps on open-ended lines, the costs of purchasing and maintaining monitoring instruments, and conducting a quarterly leak detection and repair program for pumps and valves. Table 5-3 presents RACT costs for each of the model plants. A detailed cost analysis for each type

of equipment component and monitoring instrument is presented in Appendix F. The cost estimates derived in this document are based on previous studies undertaken by the U.S. Environmental Protection Agency in the synthetic organic chemicals manufacturing industry.

The costs of implementing RACT for equipment leaks at a specific chemical processing plant are dependent upon several factors. The predominant factors include:

1) the number and type of each equipment component;
2) the type and value of the product streams controlled;
3) the choice and number of monitoring instruments purchased; and
4) the rate of occurrence and recurrence of leaking equipment.

As shown in Table 5-3, the net annualized costs to implement RACT are reasonable for the three model plants presented. The cost-effectiveness of implementing RACT improves, however, with increasing plant complexity (number of equipment components). The cost effectiveness improves with increasing plant complexity because more emission reductions are achieved to offset the annualized costs of monitoring instruments. However, the costs for a chemical processing plant smaller than (having fewer equipment components) Model Plant A, may be unreasonable.

Table 5-1. MODEL PROCESS VENT STREAMS AND APPLIED RACT METHODS

Model Process Vent	Vent Stream Characteristics: Type of VOC	VOC Emissions (Mg/yr)	Airflow (scmm)	Annual Operating Hours	RACT Control Method
I[a]	light alcohol	50[f]	71	2,000	carbon adsorber
II[b]	light alcohol	180[f]	71	2,000	carbon adsorber
III[c]	light alcohol	750[f]	425	2,000	carbon adsorber
IV[d]	chlorinated hydrocarbon	460	56	8,600	condenser
V[e]	mixed hydrocarbons	3,300	7	8,600	flare

[a]Representative of small quantities of VOC exhausted from process dryers. Discussed further in Appendix C.

[b]Representative of large quantities of VOC emissions from process dryers. Discussed further in Appendix D.

[c]Representative of large quantities of VOC released to the atmosphere from organic (i.e., alcohol) scrubber vent. Discussed further in Appendix E.

[d]Representative of a process vent stream containing a chlorinated hydrocarbon. Discussed further in Appendix F.

[e]Representative of a large exhaust vent containing a mixture of hydrocarbons. Discussed further in Appendix G.

[f]Emissions for these streams are based on 2,000 annual operating hours.

Table 5-2. SUMMARY OF RACT COST IMPACTS FOR MODEL PROCESS VENTS
(Thousands of December 1984 dollars)

Cost Item/Model Process Vent[a]	I	II	III	IV	V
Capital Cost	111	147	292	111	54
Total Annualized Cost	37	48.2	93.4	46	60
Emission Reduction, Mg/yr[b]	11	38	160	414	3,000
Product Recovery Credit[c]	(4.4)	(16.1)	(67.3)	(21)	N/A
Net Annualized Costs[d]	32.6	32.1	26.1	25	60
Cost Effectiveness, $Mg/[e]	3,000	1,850	165	60	20

N/A = Not applicable
(xx) = cost savings

[a] The cost analysis for model process vent streams I, II, III, IV, and V are presented in detail in Appendices C, D, and E, respectively.

[b] Emission reductions for model process vents I, II, and III are based on 85 percent control efficiency. A 90 percent control efficiency is assumed for vents IV and V, although only 85 percent is required. Actual emission reductions for some of the model process vents may be as high as 99 percent control. For cost analysis, emissions from streams I, II, and III are based on 2,000 operating hours per year, representing a worse case scenario.

[c] Product recovery credits for Model Vents I, II, and III are based on 85 percent control efficiency of a carbon adsorption bed and 85 percent recovery efficiency for a desorption stripper, for an overall recovery efficiency of 72.3 percent. Recovery credits are based on ethanol, thus representing a low recovery value consistent with a worse case scenario. A 90 percent recovery efficiency is assumed for condensation unit for Model Vent IV. No product recovery credits are associated with a flare used to control Vent V.

[d] Total annualized cost minus product recovery credit.

[e] Net annualized cost divided by the annual VOC emission reduction.

Table 5-3. MODEL PLANT EQUIPMENT RACT COSTS AND COST EFFECTIVENESS
(December 1984 dollars)

Equipment Component/Cost Item	Number of Components Per Model Plant[a] A	B	C	Net Annualized Cost per Component,[b] $	Model Plant Net Annualized Costs, $[c] A	B	C
Pump Seals							
Light Liquid Service	8	24	160	272	2,200	6,500	44,000
Valves							
Gas Service	99	172	900	(4.68)	(460)	(800)	(4,200)
Light Liquid Service	131	228	3,000	(3.14)	(410)	(720)	(9,400)
Safety/Relief Devices							
Gas Service	11	34	100	(209)	(2,300)	(7,100)	(21,000)
Open-Ended Lines	104	318	1,400	10	1,000	3,200	14,000
				Instrument Costs[b]	7,130	7,130	7,130
				Model Plant Net Annualized Costs	7,160	8,210	20,530
				Model Plant Emission Reductions[d] Mg/yr	12	28	169
				Model Plant Cost Effectiveness[e] ($/Mg)	600	290	180

(xx) = indicates cost savings

[a]From Table 2-4.

[b]The basis for estimating individual component and monitoring instrument costs are presented in Appendix F. The net annualized costs are based on an average product recovery credit of $620/Mg of VOC emission reductions.

[c]Calculated by multiplying the number of components per plant by the per component net annualized cost.

[d]From Table 3-1.

[e]Model plant net annualized cost divided by annual model plant emission reduction.

5.3 REFERENCES

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2. Neveril, R.B. Capital and Operating Costs of Selected Air Pollution Control Systems. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/5-80-002. December 1978.

APPENDIX A

Model Regulation

A.0 MODEL REGULATION

1200-3-18-____ CHEMICAL PROCESSING PLANT VENTS

(1) For the purpose of this rule, the following definitions apply:

(a) "Chemical processing plant" means any facility engaged in the production or use of organic compounds in the manufacture of various products.

(b) "Processing vent" means a conveyance from a vessel in a chemical processing plant that permits the passage or escape of process liquids, gases, or fumes to the atmosphere.

(2) The owner or operator of a chemical processing plant subject to this regulation shall be required to equip all process vents with the potential to emit more than 12 pounds VOC per hour with a closed vent system capable of capturing and transporting process emissions to a control device (vapor recovery system, enclosed combustion device, or flare) designed and operated to achieve an efficiency of at least 85 percent control.

(a) Flares shall be designed for and operated with no visible emissions as determined by Reference Method 22, except for periods not to exceed a total of 5 minutes during any 2 consecutive hours.

(b) Flares shall be operated with a flame present at all times as determined by the presence of a flare pilot flame to be monitored using a thermocouple or any other equivalent device to detect the presence of a flame.

(3) Owners and operators of control devices used to comply with this part shall monitor these control devices to ensure that they are operated and maintained in conformance with their designs.

(4) Closed vent systems shall be monitored to determine compliance with no detectable emissions, as indicated by an instrument reading of less than 500 ppm as above background and visual inspections, annually and at other times requested by the technical secretary.

(5) Closed vent systems and control devices used to comply with 1200-3-18____ shall be operated at all times when emissions may be vented to them.

(1) For the purpose of this rule, the following definitions apply:

(a) "Closed vent system" means a system that is not open to the atmosphere and that is composed of piping, connections, and, if necessary, flow inducing devices that transport gas or vapor from a piece or pieces of equipment to a control device.

(b) "Connector" means flanged, screwed, welded, or other joined fittings used to connect two pipe lines or a pipe and a piece of process equipment together.

(c) "Control device" means an enclosed combustion device, vapor recovery system, or flare.

(d) "Equipment" means each pump, valve, pressure relief valve, sampling connection, open-ended valve, and flange or connector in VOC service.

(e) "First attempt at repair" means to take rapid action for the purpose of stopping or reducing leakage of organic material to atmosphere using best practices.

(f) "In gas service" means that the piece of equipment contains process fluid that is in the gaseous state at operating conditions.

(g) "In light liquid service" means that the piece of equipment contains process fluid that has a vapor pressure greater than 10.3 kPa (1.5 psi) at operating conditions.

(h) "Leak percentage" means the total number of valves leaking in a process unit divided by the number of valves in gas and light liquid service within the process unit.

(i) "Open-ended valve" means any valve, except pressure relief devices, having one side of the valve in contact with process fluid and one side open to the atmosphere, either directly or through open piping.

(j) "Pressure release" means the emission of materials resulting from system pressure being greater than set pressure of the pressure relief device.

(k) "Process unit" means equipment assembled to produce intermediate or final products; a process unit can operate independently if supplied with sufficient feed or raw materials and sufficient storage facilities for the product.

(l) "Quarter" means a 3-month period.

(m) "Repaired" means that equipment is adjusted, or otherwise altered, in order to eliminate a leak as indicated by one of the following: an instrument reading of 10,000 ppm or greater, indication of liquids dripping, or indication by a sensor that a seal or barrier fluid system has failed.

(n) "In vacuum service" means that equipment is operating at an internal pressure which is at least 5 kilopascals (kPa) below ambient pressure.

(o) "In VOC service" means that the piece of equipment contains or contacts a process fluid that is at least 10 percent VOC by weight.

(2) Each owner or operator subject to the provisions of the subpart shall demonstrate compliance with the requirements of Chapter 1200-3-10- _____ Sections (3) to (11).

(a) Compliance will be determined by review of records and reports, and inspection using the methods and procedures specified in Reference Method 21.

(b) Equipment that is in vacuum service, controlled by means of a closed vent system, or determined to achieve an equivalent emission limitation, is exempt from the requirements of Sections (3) to (6).

(c) Each component subject to the requirements of 1200-2-18- ____ shall be marked in some manner that will be readily obvious to both plant personnel and the Technical Secretary, and have an identification number.

(d) Any component in VOC service that appears to be leaking on the basis of sight, smell, or sound, shall be repaired with an initial attempt as soon as possible and final repair within 15 calendar days.

(e) A weatherproof and readily visible identification marked with the equipment identification number shall be attached to leaking equipment.

(f) Chemical processing plants having fewer than 250 valves in VOC service are exempt from the requirements of Sections (3) to (6).

(3) Pumps in light liquid service:

(a) shall be monitored quarterly to detect leaks by the methods specified in Reference Method 21.

(b) shall be checked by visual inspection each calendar week for indications of liquids dripping from the pump seal.

(c) if an instrument reading of 10,000 ppm or greater is measured, or if there are indications of liquids dripping from the pump seal, a leak is detected.

(d) when a leak is detected, it shall be repaired as soon as possible, but no later than 15 calendar days after it is detected, except as provided in Section (7).

(4) Valves in gas and light liquid service:

(a) shall be monitored quarterly to detect leaks by the methods specified in Reference Method 21, except as provided in Sections (4)(d) and (4)(e).

(b) If an instrument reading of 10,000 ppm or greater is measured, a leak is detected.

(c) When a leak is detected, it shall be repaired as soon as possible, but no later than 15 calendar days after the leak is detected.

(d) Certain valves would be exempt from (4) provided:

1. an owner or operator demonstrates that a valve cannot be monitored without elevating the monitoring personnel more than 2 meters above a support surface.

2. A valve has no external actuating mechanism in contact with the process fluid.

(e) An owner or operator may elect to have the valves comply with alternative requirements to Section 1200-3-180 (4)(a) provided:

1. An owner or operator must notify the Technical Secretary in writing that the owner or operator has elected to have the valves comply with an alternative requirement for valves; and

2. An owner or operator shall not have a process unit with a leak percentage greater than 2.0 percent; or

3. After 2 consecutive quarterly leak detection periods with the percent of valves leaking equal to or less than 2.0, an owner may skip 1 of the quarterly leak detection periods, or after 5 consecutive quarterly leak detection periods with the percent of valves leaking equal to or less than 2.0, an owner or operator may begin to skip 3 of the quarterly leak detection periods.

4. Owners or operators shall not have a process unit with a leak percentage greater than 2.0 percent.

5. A performance test shall be conducted initially, annually, and at other times requested by the Technical Secretary.

(5) Pressure relief valves in gas service:

(a) shall be monitored quarterly to detect leaks by methods specified in Reference Method 21.

(b) if an instrument reading of 10,000 ppm or greater is measured, a leak is detected.

(c) when a leak is detected, excluding overpressure releases, it shall be repaired as soon as possible, but not later than 15 calendar days after it is detected.

(6) Open-ended valves:

(a) shall be equipped with a cap, blind flange, plug, or second valve, except during operations requiring flow through the open valve.

(b) shall be operated in a manner such that the valve on the process fluid end is closed before the second valve is closed.

(c) open-ended valves which serve as a sampling connection shall be equipped with a closed purge system or closed vent system such that:

1. purged process fluid be returned to the process line with zero emissions to atmosphere, or

2. collect and recycle the purged process fluid with zero emissions to atmosphere.

(7) Delay of repair:

(a) Delay of repair of equipment for which leaks have been detected will be allowed if repair is technically infeasible without process unit shutdown. Repair of this equipment shall occur before the end of the next process unit shutdown.

(b) Delay of repair of equipment will be allowed for equipment which is isolated from the process and which does not remain in VOC service.

(c) Delay of repair for valves will be allowed if the owner or operator demonstrates that emissions of purged material resulting from immediate repair are greater than the fugitive emissions likely to result from delay of repair, and when repair procedures are effected, the purged material is

collected and destroyed or recovered in a control device or collected and recycled with zero emissions to atmosphere.

(8) The owner or operator of a chemical processing plant shall maintain monitoring records for all components subject to the requirements of this part.

(a) This log shall contain at a minimum the following data:

1. the type of component,

2. the location of the component,

3. the identification number of the component,

4. the date on which a leaking component is discovered, initial repair attempted, and the component is repaired,

5. the date and instrument reading of the recheck monitoring after a leaking component is repaired,

6. a record of the calibration of the monitoring instrument, and

7. the identification of components awaiting repair according to (7).

(b) Copies of the monitoring log shall be retained by the owner or operator for a minimum of 2 years after the date on which the record was made or the report prepared.

(c) Copies of the monitoring log shall immediately be made available to the Technical Secretary upon verbal or written request, at any reasonable time.

(9) The owner or operator of a chemical processing plant shall submit quarterly reports to the Technical Secretary.

(a) The quarterly reports shall include:

1. the total number of components inspected,

2. the total number of components found leaking,

3. the total number of components awaiting repair per delay of repair provisions.

(10) The Technical Secretary, upon written notice, may modify the monitoring, recordkeeping, and reporting requirements.

APPENDIX B

Enforcement Aspects

B.0 ENFORCEMENT ASPECTS

The model regulations for chemical processing plants require: (1) a closed vent system to a VOC control device and (2) an inspection and maintenance program to reduce emissions from leaking equipment. These requirements rely on visual inspections and on records maintained by the source to monitor compliance. Factors important to assessing compliance with the regulations are discussed below.

B.1 PROCESS VENT REQUIREMENTS

The recommended requirement of 85 percent control efficiency of chemical processing plant vent streams will likely be implemented through use of a wide variety of control devices. There are several techniques for testing the efficiency of VOC control devices. Applicable test methods are summarized in Table B-1.

Table B-1 presents information on test methods and their applicability to particular process streams. The complete test method may be found in either the Federal Register (Part 11, Environmental Protection Agency; Standards of Performance for New Stationary Sources; Bulk Gasoline Terminals, August 18, 1983) or the Code of Federal Regulations (vol. 40, Parts 53 to 80, revised July 1, 1984).

B.2 INSPECTIONS AND MAINTENANCE PROGRAM

Compliance with the inspection and maintenance program shall be determined through inspection of the monitoring logs of the components subject to the standard and the quarterly reports on the inspections and repairs during the record period. The standards require monitoring of equipment using a hydrocarbon analyzer and the methods specified in EPA Reference Method 21. The criteria for definition of leaks from equipment are based on studies conducted as part of the development of standards of performance on petroleum refineries.[1] These studies demonstrated that a leak definition of 10,000 ppm will detect approximately 90 percent of the mass emission from valves and will identify with a high degree of certainty any pumps with seal failures.[1]

B.3 REFERENCES

1. Petroleum Fugitive Emissions - Background Information for Promulgated Standards. U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-450/3-81-015b. October 1983.

Table B-1. SUMMARY OF TEST METHODS

Method	Applicability and Principle
2 Determination of stack gas velocity and volumetric flow rate (Type S Pitot Tube)	This method is used to measure average gas velocity in a stack and for quantifying gas flow rate. This is determined from the gas density and measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube. This method is not applicable at measurement sites other than ducts, stacks, or flues. It also cannot be used in cyclonic or swirling gas streams.
2A Direct measurement of gas volume through pipes and small ducts	Measurement of gas flow through pipes and small ducts either in-line or exhaust positions temp range of 0-50°C (32-125°F). Uses a gas volume meter with corrections made for local temperature and pressure conditions.
2B Determination of exhaust gas volume flow rate from gasoline vapor incinerators	Method applies to the measurement of exhaust volume flow rate from incinerators that process gasoline vapors consisting of alkanes, alkenes and/or aromatic hydrocarbons. The amount of auxiliary fuel is negligible. This method uses a carbon balance from inlet concentration (hydrocarbons); to outlet carbons in the form of combustion products C_n, CO, CO_2, to determine flow rate.
25 Determination of total gaseous nonmethane organic emissions as carbon	This method applies to the measurement of volatile organic compounds (VOC) as total gaseous nonmethane organics (TGNMO) as carbon in source emissions. An organic particulate filter may be needed as particulate will interfere with the test results. An emission sample is withdrawn from the stack of a constant rate through a chilled condensate trap by means of an evacuated sample tank. TGNMO is determined by combining the analytical results from independent analysis of the condensate trap and sample tank fractions.

Table B-1. SUMMARY OF TEST METHODS (Continued)

Method	Applicability and Principle
25A Determination of total gaseous organic concentration using a flame ionization analyzer	Applies to the measurement of total gaseous organic concentration of vapors consisting primarily of alkanes, alkenes, and/or aromatic hydrocarbons. The concentration is expressed either in terms of propane (or other appropriate gas) or in terms of carbon. A gas sample is extracted from the source through a heated process line, if necessary, and glass fiber filter to a flame ionization analyzer (FIA). Results are reported as volume concentration equivalents of the calibration gas or as carbon.
25B Determination of total gaseous organic concentration using a nondispensive infrared analyzer	This method is used to measure the total gaseous organic concentration of alkane vapors. Other vapors may be measured using the general procedure in this method. The concentration is expressed either in terms of propane or carbon. A gas sample is extracted through a heated sample line, if necessary, and glass fiber filter to a nondispensive infrared analyzer. Reports are given in volume concentration equivalents of the calibration gas (or other appropriate gas) or in terms of carbon.

APPENDIX C

Carbon Adsorption Cost Analysis

C.0 CARBON ADSORPTION COST ANALYSIS

C.1 INTRODUCTION

This appendix presents the basis for the cost analysis for carbon adsorption techniques used to control VOC emissions from three model process vents (I, II, and III), presented in Chapter 5.0 of this document.

All three streams represent a typical emission vent from a drying operation in a chemical plant. The streams vary in the quantity of VOC's emitted, but all three are assumed to be composed of ethanol vapors and air. For light alcohol streams, such as ethanol, methanol, or isopropyl alcohol, emission reductions on the order of 85 percent can be expected for carbon adsorption techniques.[1,2,3] For purposes of ethanol recovery, the desorption stripper efficiency has been estimated at 85 percent. Thus, overall recovery efficiency (product recovery credit) is estimated as the product of the adsorber efficiency and stripper efficiency, or 72.3 percent. This means that for every 100 pounds of alcohol vented to the carbon adsorber system, 85 pounds will be adsorbed in the carbon unit of which 72.3 pounds will eventually be recovered for resale in the stripper unit. The capital costs for the three model streams range from $111,000 for the smallest system (capable of handling 7 kg/hr) to almost $300,000 for the largest system, capable of handling 100 kg/hr. Each stream is assumed to be at ambient temperature, with no significant particulate content. Stream I is assumed to emit 6 Kg VOC/hr; Stream II, 23 Kg VOC/hr; and Stream III, 91 Kg VOC/hr.

C.2 CAPITAL COSTS

The capital costs for implementing RACT are based on the purchase and installation of an activated carbon adsorption system. The system includes a stripper to reclaim the organics from the desorbed carbon bed. The purity of the reclaimed organics is not expected to be high, thus, further separation equipment may be necessary to reclaim pure products. It is assumed that the effluent stream from the stripper containing organics is not an emission source. Hence, the emission reduction of the control system is equal to the control efficiency of the carbon adsorber, 85 percent. Table C-1 gives a detailed capital cost analysis for the three proposed carbon systems.

Table C-1. CAPITAL COST ANALYSIS FOR CARBON ADSORPTION TECHNIQUES
(Thousands of December 1984 dollars)

Cost Items	Model Process Vent	I	II	III
Direct Costs				
1) Purchased Equipment Costs				
	Carbon Recovery Unit[a]	80	105	210
	Taxes[b]	2.4	3.2	6
	Freight[c]	4	5.2	11
2) Installation Direct Costs				
	Electrical[d]	3.2	4.2	8.4
	Piping[e]	1.6	2.1	4.2
	Site Preparation[e]	1.6	2.1	4.2
Indirect Costs				
3) Installation Indirect Costs				
	Engineering and Supervision[f]	8	11	21
	Construction Fee[f]	8	11	21
	Contingencies[g]	2.4	3.2	6
TOTAL INSTALLED CAPITAL COSTS		111	147	292

[a] Reference 3.

[b] Taxes are estimated as 3 percent of carbon adsorption unit. Reference 4.

[c] Freight is estimated as 5 percent of carbon adsorption unit. Reference 4.

[d] Electrical is estimated as 4 percent of carbon adsorption unit. Reference 4.

[e] Piping and site preparation are estimated as 2 percent of carbon adsorption unit. Reference 4.

[f] Engineering and supervision costs and construction fee costs are estimated as 10 percent of carbon adsorption unit. Reference 4.

[g] Contingencies are estimated as 3 percent of carbon adsorption unit. Reference 4.

C.3 ANNUALIZED COSTS

The annualized costs of implementing RACT are based on Reference 4 and results of Table C-1. The net annualized cost includes product recovery credit for reclaimed ethanol. Since the purity of this ethanol is not expected to be high, the lowest grade of ethanol given in the Chemical Marketing Reporter has been used to calculate product recovery credit. Table C-2 gives the estimated annualized costs for the three carbon systems.

The annualized costs for the three model streams range from $37,000 for the smallest stream to $93,400 for the largest stream.

Table C-3 summarizes the product recovery credits estimated from the alcohol recovery of the stripper. The product recovery credits are based on 2,000 operating hours per year. The 2,000 operating hours per year reflects actual operating conditions for similar vent streams in Shelby County, Tennessee, but not necessarily anywhere else. If the operating hours are actually nearer 8,000 (which the equipment is sized for), the net annualized costs would be considerably less due to increased product recovery credits. Table C-4 presents the net annualized costs, which is the difference between annualized costs and product recovery credits. Figures are again based on 2,000 operating hours per year.

Table C-2. ANNUALIZED COST ANALYSIS FOR CARBON ADSORPTION TECHNIQUES
(Thousands of December 1984 dollars)

Cost Items	Model Process Vent	I	II	III
Direct Operating Costs				
1)	Operating Labor Maintenance and Materials[a]	7	9	18
2)	Utilities Electricity[b]	1	1	1
	Other[c]	1	1	1
Indirect Operating Costs				
4)	Overhead[d]	5.6	7.2	14.4
5)	Property Tax[e]	1.1	1.5	3
6)	Insurance[e]	1.1	1.5	3
7)	Administration[f]	2.2	3	6
8)	Capital Recovery Cost[g]	18	24	47
TOTAL ANNUALIZED COSTS		37	48.2	93.4

[a] Based on 6 percent of Total Installed Capital Costs. Reference 6.

[b] Based on 1,000 kWh/month and $0.06 kWh. Reference 4.

[c] Includes steam, water, plant air. Assumed to be same as electricity.

[d] Based on 80 percent of operating labor, maintenance, and materials. Reference 4.

[e] Calculated as 1 percent of capital costs. Reference 4.

[f] Calculated as 2 percent of capital costs. Reference 4.

[g] Calculated as: Capital recovery factor x capital cost. Capital recovery factor based on 10 percent interest and 10 years:

$$\frac{i\,(1+i)^n}{(1+i)^n - 1} = 0.163$$

Table C-3. BASIS FOR PRODUCT RECOVERY CREDITS

Basis

1) Adsorber efficiency = 85 percent
2) Stripper efficiency = 85 percent
3) Overall recovery efficiency = 0.85 = 72.3 percent
4) Annual operating hours = 2000 hrs.
5) Ethanol price $1.48/gal[a]
6) Product recovery credit:

$$\frac{\$1.48}{\text{gal}} \times \frac{\text{gal}}{3.785\ \text{l}} \times \frac{\text{l}}{1000\ \text{ml}} \times \frac{\text{ml}}{0.7893} \times \frac{1{,}000{,}000\text{g}}{\text{Mg}} = \$495/\text{Mg}$$

Stream I:	
Uncontrolled VOC emissions[b]	12.5 Mg/yr
VOC emission reduction[c]	11 Mg/yr
Recovered ethanol[d]	9 Mg/yr
Recovery credit[e]	$4,400/yr
Stream II:	
Uncontrolled VOC emissions[b]	45 Mg/yr
VOC emission reduction[c]	38 Mg/yr
Recovered ethanol	32.5 Mg/yr
Recovery credit	$16,100/yr
Stream III:	
Uncontrolled VOC emissions[b]	188 Mg/yr
VOC emission reduction[c]	160 Mg/yr
Recovered ethanol	136 Mg/yr
Recovery credit	$67,300/yr

[a]Ethanol price reflects lowest grade available. Reference 3.

[b]Assumed annual uncontrolled VOC emissions.

[c]Calculated as 85 percent of annual uncontrolled VOC emissions.

[d]Calculated as 72.3 percent of annual uncontrolled emissions.

[e]Calculated as $495/Mg recovered ethanol.

Table C-4. NET ANNUALIZED COSTS
(Thousands of December 1984 dollars)

Cost Item	Model Process Stream	I	II	III
Total Annualized Costs[a]		37	48.2	93.4
Product Recovery Credits[b]		4.4	16.1	67.3
Net Annualized Costs[c]		32.6	32.1	26.1

[a] From Table C-2.

[b] From Table C-3.

[c] Difference between annualized costs and product recovery credit.

C.4 REFERENCES

1. Telecon, Sink, M., Pacific Environmental Services, Inc., to R. Dievendort, Union Carbide. March 11, 1985.

2. Telecon. Sink, M., Pacific Environmental Services, Inc., to J. Minor, M and W Mechanical Engineering. Controls for light alcohol mixes. March 12, 1985.

3. Telecon. Sink, M., Pacific Environmental Services, Inc., to T. Cannon, VIC Manufacturing Co. Costs of Carbon Adsorber Systems. March 12, 1985.

4. Neveril, R.B. Capital and Operating Costs of Selected Air Pollution Control Systems. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/5-80-002. December 1978.

5. Chemical Marketing Reporter. Price of low grade ethanol. Schnell Publishing Co., Inc. Vol. 227, No. 2. p. 37. January 14, 1985.

6. Organic Chemical Manufacturing vol 5: Absorption, Condensation, and Adsorption Devices. U.S. Environmental Protection Agency. Publication No. EPA-450/3-80-027. December 1980.

APPENDIX D

Condenser Unit Cost Analysis

D.0 CONDENSER UNIT COST ANALYSIS

D.1 INTRODUCTION AND SUMMARY

This appendix presents the basis for estimating the costs of controlling a hypothetical chlorinated hydrocarbon vent emissions source at a chemical processing plant. The basis of this cost analysis is Model Vent IV presented in Chapter 5. The following memorandum summarizes the vent stream characteristics and condenser unit costs estimated from a computer program. A full discussion of the model can be found in the background information document for proposed new source performance standards for the polymer manufacturing industry - EPA publication No. 450/13-83-019 (Draft October 1984).[1]

Controlling the emission source by condensation appears to be very cost effective. Table D-1 summarizes the estimated capital costs, annualized costs, and cost effectiveness. The annualized cost does not include product recovery credit. It is estimated that product recovery credit from this source can be as much as $21,100/yr with 90 percent control efficiency.

Assume all emission reductions as product recovery credits
Based on 90 percent emission reduction

Total Emissions: 430 Mg/yr
Emission Reduction: 414 Mg/yr

CCl_4 price[2]: $\$0.31/gal \times \frac{264.17\ gal}{1{,}000\ l} \times \frac{1}{1{,}000\ ml} \times \frac{ml}{1.595\ g}$

$$\times \frac{1{,}000{,}000\ g}{Mg}$$

$$= \$51/Mg$$

$$\frac{\$51}{Mg} \times 414\ \frac{Mg}{yr} = @21{,}100/yr \text{ Product Recovery Credit}$$

This credit assumes that there are no other costs incurred in shipping recovered chlorinated hydrocarbon for resale.

Table D-1. COST ANALYSIS FOR CONDENSER UNIT
(December 1984 dollars[3])

Cost Item/Estimated Cost	
Total Capital Costs[a]	111,000
Totl Annualized Costs[a]	46,150
Cost Effectiveness ($/Mg)[b]	111

[a] Updated costs from memorandum calculated from Chemical Engineering Cost Indexes. Reference 3.

[b] Cost effectiveness does not include product recovery credit.

M E M O R A N D U M

DATE: April 11, 1985

TO: Tom Rhoads, Pacific Environmental Services, Inc.

FROM: Ken Meardon, Pacific Environmental Services, Inc.

SUBJECT: Control of Carbon Tetrachloride (CCl_4) Stream Using a Condenser

- -

The condenser analysis program developed for the polymer manufacturing NSPS was used to size and cost a condenser for removing 90 percent of CCl_4 from an emission stream. In the absence of specific information, the emission stream was assumed to be saturated CCl_4 in air. Total CCl_4 emissions were 460 Mg (506 tons) per year. The results of the analysis are summarized in Attachment 1. Briefly, a gas outlet temperature of about 6°F is required to reduce emissions by 90 percent. A Freon-12 coolant was selected to provide the cooling capacity. A heat exchanger with about 360 ft^2 was estimated and, incorporating conservative design assumptions, a 440 ft^2 heat exchanger was selected for costing purposes. The total capital cost of the heat exchanger and refrigeration system was calcuated to be $88,636 (June 1980 dollars). Total annual costs were calculated to be $36,895 (June 1980 dollars). This does not include any recovery credit that might be assigned to the recovered CCl_4. (Attachment 2 presents the assumptions used for calculating the annual costs.) As the condenser recovers 90 percent of the CCl_4 (i.e., 414 Mg), the average cost effectiveness of the control is $89/Mg of CCl_4 recovered.

Attachment I

CONDENSATION SYSTEM DESIGN SUMMARY

Production capacity, Gg/yr	230
Operating hours per year	8600
Inlet emission factor, kg VOC/Mg product	2
Emission reduction	90.0%
Outlet emission factor, kg VOC/Mg product	0.2
Inlet temperature, deg.F	80
Inlet pressure, atmospheres	1
Inlet styrene mass flow rate, lb/hr	117.92
Inlet gas stream volumetric flow rate, acfm	32.36
Gas outlet temperature required for reduction, deg.F	6.13
Coolant temperature selected, deg.F	0
Design heat load, Btu/hr	12773
Code for coolant selected (1 = Freon-502; 2 = Freon-12; 3 = 1/2 ethylene glycol & 1/2 water; 4 = water)	3
Required condenser area, sq.ft	362.87
Selected condenser area, sq.ft	448.28
Heat exchanger actual inner shell diameter, in.	23.25
Length of heat exchanger, ft	8.000
Number of tubes in heat exchanger	217
Tube outer diameter, in.	1
Tube cross-sectional area, sq.ft per tube	0.004128
Coolant specific gravity (relative to water at 60 deg.F)	1.454
Coolant flow in heat exchanger, gpm	1206.29
Coolant temperature change, deg.F	0.067
Required refrigeration capacity, tons of refrigeration	1.0644
Selected refrigeration capacity, tons of refrigeration	NA
Selected refrigeration capacity, compressor horsepower	3.0000
Horsepower per ton of refrigeration for coolant temperature	2.192

CAPITAL AND ANNUAL OPERATING COST ESTIMATION

Capital Costs

Heat exchanger	
Installed cost per Enviroscience, December 1979	$76,391
Installed cost per vendors, July 1984 (est.)	NA
Installed cost, June 1980	$79,969
Refrigeration	
Installed cost per Enviroscience, December 1979	NA
Installed cost per vendors, June 1980 (est.)	$8,667
Installed cost, June 1980	$8,667
Total Installed Capital Cost, June 1980	$88,636

Annualized Costs

Operating labor	$1,076
Maintenance materials & labor	$4,432
Utilities	
Electricity, pumping	$10,703
Electricity, refrigeration	$1,015

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Coolant, make-up	$1,702
Capital recovery	$14,421
Taxes, administration, & insurance	$3,545
Total annualized cost without recovery credit	$36,895
CCL4 recovery credit	$0
Net Annualized Cost (after recovery credit)	$36,895
CCL4 Emission Reduction, Mg/yr	414.32
Average Cost Effectiveness, $/Mg	$89

VARIABLES	VALUES
Production Capacity, Gg/yr	8.4E
Inlet Emission Factor, kg VOC/Mg product	2
Emission Reduction	90.0%
Operating Hours per Year	8600
Hourly Production Rate, Mg/hr	1.74
Minimum Heat Exchanger Design Safety Margin	10%
Initial Guess of Overall Heat Transfer Coefficient, Btu/sq.ft-hr-deg.F	3
Initial Guess of Sectional Heat Exchanger Size Code [use Alt-K] (** MUST SET AT ZERO & USE ALT-C TO CALCULATE OVERALL SIZE **)	1
Assumed Coolant (Tube-side) Velocity, ft/sec	3
Assumed Ratio of Bulk to Wall Coolant Dynamic Viscosity	1
Ratio of Bulk to Wall Coolant Viscosity to 0.14 Power	1
Assumed Initial Condensate Film Temperature:amount greater than coolant temperature plus tube-side temp. increase, deg.F	15
Assumed Shell-side Fouling Coefficient	0.001
Assumed Tube-side Fouling Coefficient	0.001
Number of Sections Considered in Heat Exchanger Analysis	6
Thermal Conductivity of Admiralty Brass (Perry's p.23-49), Btu/hr-ft-deg.F	64.2
Reduction in Effective Tube Length per each of 2 Tube Sheets, inch	
for shell diameters)= 8 in.	1.5
for shell diameters (8 in.	0.25

CONSTANTS & CONVERSION FACTORS	VALUES
Kilograms per pound	0.4536
Minutes per hour	60
Seconds per hour	3600
Gallons per cubic foot	7.48
Freezing temperature of water, deg. F	32
Absolute zero temperature, deg. F	-459.67
Absolute zero temperature, deg. C	-273.15
Ratio of 1 deg. F to 1 deg. C	1.8
Number of mm Hg per atmosphere pressure	760
Number of psi per atmosphere pressure	14.696
Number of inches per foot	12
Number of sq. in. per sq. ft	144
Number of lb/cu.ft per g/ml	62.43
Btu/lb-deg.F per cal./g-deg.C	1
Gas constant, cal/g-mole - deg. K	1.9853
Gas constant, ft-lb/lb-mole - deg. R	1545
Density of air at 0 deg. C, lb/cu. ft	0.0808
Acceleration due to gravity, ft/hr-hr	4.17E+08
Dynamic viscosity: lb/ft-hr per microppoise	2.419E-04
Dynamic viscosity: microppoise per centipoise	10000
Thermal conductivity: Btu/hr-ft-deg.F per cal/sec-cm-deg.C	241.909
Refrigeration Capacity: Btu/hr per ton	12,000

Costing Constants & Assumptions	Value
Operating labor (w/o supervision) for)20 sq.ft units, hr/wk	1
Operating labor (w/o supervision) for (20 sq.ft units, hr/mon	2
Hourly rate for operating labor (including overtime), $/hr	18
Supervisory labor, % of operating labor	15%
Assumed pumping height, ft	50
Assumed pump efficiency	65%
Assumed compressor efficiency	85%

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Assumed motor efficiency	85%
Kilowatts per horsepower	0.7457
Cost of 1 kilowatt-hour	$0.049
Cost of water, $/1000 gal	0.50
Make-up requirement for chilled water, % of annual flow	0.1%
Annual make-up requirement for ethylene-glycol brine solutions & Freon, replacements of condenser & refrigeration volume	1
Ratio of condenser & refrigeration system volume to condenser volume	2
Cost of ethylene glycol, $/lb	$0.27
Cost of Freon-12, $/lb	$1.31
Cost of Freon-502, $/lb	$3.11
Percent of reduced methanol emissions recovered	90%
Recovery credit for methanol, $/lb	$0.068
Capital recovery factor (10%,10 years)	0.1627
Cost of maintenance mat'ls & labor, % of total installed cost	0.05
Cost of taxes, admin. & insurance, % of total installed cost	0.04
Chemical Engineering Plant Cost Index, June 1980	259.2
Chemical Engineering Plant Cost Index, December 1979 (Envir.)	247.6
Chem. Eng. Fabricated Equipment Cost Index, June 1980	291.3
Chem. Eng. Fabricated Equipment Cost Index, July 1984 (est.)	334.6
Weeks per year	52
Months per year	12
Pounds per megagram	2204.5
Ratio of installed cost to purchase cost, for vendor costs	1.39
Chem. Eng. Prod. Prices Industrial Chemicals Index, June 1980	327.3
Chem. Eng. Prod. Prices Industrial Chemicals Index, May 1984	344.8

Attachment 2

Calculation of Annual Costs

Cost Item	Costing Estimate
Operating Labor	o If selected heat exchanger size is less than 34 ft^2, then cost is based on 2 hours per month for operating labor, 0.3 hours per month for supervisory labor, 12 months per year, and an overall wage rate of $18 per hour. o If selected heat exchanger size is greater than 34 ft^2, then cost is based on 1 hour per week for operating labor, 0.15 hours per week for supervisory labor, 52 weeks per year, and an overall wage rate of $18 per hour.
Maintenance materials and labor	o Based on 5 percent of total installed capital cost.
Electricity, pumping	o Calculated as follows: Assumed pumping height (50 ft) x coolant specific gravity x [coolant flow in heat exchanger (gpm) ÷ 3,960] x 0.7457 kilowatts per horsepower x (operating hours per year ÷ assumed pumped efficiency) x $0.049 per kilowatt-hour.
Electricity, refrigeration	o Calculated as follows: Required refrigeration capacity (tons) x [horsepower per ton of refrigeration for coolant temperature ÷ ( )assumed compressor efficiency (0.85) x assumed motor efficiency (0.85))] x 0.7457 kilowatt per horsepower x operating hours per year x $0.049 per kilowatt-hour.
Coolant make-up	o For Freon-12, cost = (coolant specific gravity x 62.37 x $1.31 per lb).
Capital recovery	o Based on 10 percent interest and 10 year life (0.1627 x total installed capital cost).
Taxes, Administration, and Insurance	o 0.04 x total installed capital cost.

D.1 REFERENCES

1. Background Information Document NSPS for the Polymer Manufacturing Industry. EPA Publication No. 450/13-83-019. October 1984.

2. Chemical Marketing Reporter. Price of technical grade carbon tetrachloride. Schnell Publishing Co., Inc. Vol. 227, No. 2. p. 35. January 14, 1985.

3. Compilation of Cost Indexes. Chemical Engineering.

APPENDIX E
FLARE COST ANALYSIS

E.0 FLARE COST ANALYSIS

E.1 INTRODUCTION AND SUMMARY

This appendix presents the basis for estimating the costs of controlling Model Vent V using a flare. The following memorandum summarizes the algorithm used to estimate flare costs.

Using a flare to control this process vent stream is technically feasible. The total annual costs are estimated at $60,000 for a 100-foot flare including a flare maintenance program. The cost effectiveness of controlling Model Vent V with a flare is estimated at about $20/Mg ($18/ton). Table E-1 gives the estimated capitalized costs, annualized costs, estimated emission reductions, and cost effectiveness. There is no product recovery credit when flares are used.

The capital costs were updated from August 1978 dollars to December 1984 dollars through use of cost indexes. Similarly, the annualized costs, originally in June 1980 dollars, were updated to December 1984 dollars.

Table E-1. COST ANALYSIS FOR FLARE UNIT
(December 1985 dollars)

Cost Item	Estimated Cost
Total Capital Costs	54,000
Total Annual Costs	60,000
Emission Reduction, Mg/yr	3,000
Cost Effectiveness, $/Mg	20

MEMORANDUM

Date: March 15, 1985

TO: Tom Rhoads, PES, Inc.

FROM: Ken Meardon, PES, Inc.

SUBJECT: Flaring of Emission Stream with MMA, PES Project 727

Using the basic flare costing procedures developed for the Polymer Manufacturing NSPS, I calculated a total annualized cost of about $48,000 (see attached worksheet). A 30-foot flare with a 2-inch diameter head would be needed. Assuming 90% efficiency, an emission reduction of 3,266 tons per year would be achieved. This works out to a cost effectiveness of slightly less than $15 per ton.

A conversation with Mr. Ed Fowler of NAO (see attached phone conversation) pointed out several things. First, SO_2 and CO are toxic gases and are subject to state and federal regulation. As the current stack is 100 feet, I calculated the cost of installing a 100-foot flare that would act as a 100-foot stack in case of flame out or other downtime. A 100-foot flare would increase the capital cost of the flare from $12,500 to $54,000. Annualized costs would increase from $4,140 to $13,300. As emission reduction remains the same, the cost effectiveness would increase to about $17.5/ton.

Second, Mr. Fowler pointed out that the presence of MMA presents a pluggage problem that is most likely manageable through more frequent maintenance of the flare. I have assumed that maintenance costs would be 8% of total capital costs rather than 4% and applied the percentage to the 100-foot flare. Thus, with maintenance costs at $4,700 (vs. $900 with 30-foot flare), total annualized costs with the 100-foot flare and increased maintenance costs would be about $60,000. This yields a cost effectiveness of about $18 per ton.

Third, Mr. Fowler pointed out several ways to reduce noise, if it is a problem. If combustion noise is a problem, this could be alleviated by enclosing the flare. A ballpark guess by Mr. Fowler was that a cost effectiveness of $15/ton might increase to $100 per ton. Applying this same ratio to the $18/ton yields a cost effectiveness of about $120/ton (backcalculating from $12/ton, the capital cost of the flare would be about $1.6 million dollars). Mr. Fowler noted that if steam noise is the problem, it could be alleviated using an acoustical flare header. This will increase costs, but nowhere near the increase if an enclosed flare is used. Mr. Fowler did not think the third noise source (jet noise) would be a problem with the exit gas velocity from the stack at

52 feet per second. Since the calculated exit velocity for the flare is about 50 feet per minute, jet noise is very unlikely to be a problem.

In summary, flaring of this stream appears to be very cost effective. Although MMA can cause pluggage, maintenance should be able to take care of the problem.

KEY TO FLARE COSTING WORKSHEET:

scfm = standard cubic feet per minute

w.g. = waste gas

$Q_{w.g.}^{scfm}$ = flow rate of waste gas (w.g.) in scfm

$LHV_{w.g.}^{scf}$ = lower heating value of waste gas, BTU per scf

$T_{w.g.}$ = temperature of waste gas, ^{o}F

$MW_{w.g.}$ = molecular weight of waste gas

$Q_{n.g.}^{scfm}$ = flow rate of natural gas (n.g.) in scfm

$Q_{fl.g.}^{scfm}$ = flow rate of the flared gas stream (fl.g.) in scfm

$LHV_{fl.g.}$ = lower heating value of the flared gas stream, BTU per scf

$T_{fl.g.}$ = temperature of the flared gas stream, ^{o}F

$MW_{fl.g.}$ = molecular wieght of the flared gas stream

V_e^{design} = design exit velocity

V_e^{actual} = actual exit velocity

D = diameter of the flare head

H = height of the flare

C_p = cost of piping

C_d = cost of ducting

C_{fl} = cost of flare

C_{sys} = cost of system (piping + ducting + flare)

FLARE COST CALCULATIONS

$Q_{w.g.}^{scfm}$	4.3 ft/sec x 60 sec/hr	258
$LHV_{w.g}^{scf}$	% vol. x Btu/lb x lb/ft^3	1,059
$T_{w.g.}$	Basis for estimate confidential	86°F
MW w.g.	Basis for estimate confidential	42.86
$Q_{n.g.}^{scfm}$	= 0, if LHV w.g. $\geq$ 115	0
	$= \frac{115 - LHV_{w.g.}^{scf} \; Q_{w.g.}^{scfm}}{815}$, if $LHV_{w.g.}^{scf} < 115$	
$Q_{fl.g.}^{scfm}$	$= Q_{w.g}^{scfm} + Q_{n.g.}^{scfm}$	258
LHV fl.g.	= 115, if Q n.g. > 0	1,059
	= LHV w.g., if Q n.g. = 0	
T fl.g.	= 70 if Q n.g. = 0 or T w.g. 70	70
	$= \frac{(Q_{w.g.} \times MW_{w.g.} \times T_{w.g.}) + (Q_{n.g.} \times 1{,}218)}{(Q_{w.g.} \times MW_{w.g.}) + (17.4 \times Q_{n.g.})}$ if Q n.g. > 0	
MW fl.g.	= MW w.g., if Q n.g. = 0	42.86
	$= \frac{(Q_{w.g.} \times MW_{w.g.}) + (17.44 \times Q_{n.g.})}{Q_{w.g.} + Q_{n.g.}}$, if Q n.g. > 0	

To select D:

$$V_e^{design} = 125\sqrt{\frac{J_{fl.g.} + 460}{MW_{fl.g.}}}$$ 439.6

D (in) $= (1.582 \times 10^{-2})\sqrt{Q_{fl.g.}^{scfm} \times MW_{fl.g.}}$ 1.66

May select 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, or 24 inches

calculated 1.66 inches selected 2 inches

After selecting D:

$$V_e^{actual} = (5.766 \times 10^{-3}) \frac{Q_{fl.g.}^{scfm}}{D^2_{sel.}} (T_{fl.g.} + 460) \qquad 50.76$$

$$\Delta P = (1.818 \times 10^{-4}) V_e^{act.^2} \qquad 0.46842$$

$$\Theta = TAN^{-1} \frac{88.2}{V_{e\ act}} \qquad 60.08$$

$$H\ (ft) = (0.02185) \sqrt{Q_{fl.g.}^{scfm} + LHV_{fl.g.}^{scf}} - (6.05 \times 10^{-3}) \times D \times V_e^{act} \times \cos\Theta$$

calculated 0.5 (ft) — selected minimum of 30, multiples of 5 — 30

Purchase Cost

if $20 \leq 40$ ft, $= (3905.7) + (35.054)\,HD + (900.36)D - (126.08)D^2$ — 7,305

if $40 \leq H \leq 200$ ft, $= 6275.6 + (224.1) + (12.782)HD + (24.856)D^2$

or use tables if available

Installed cost, C fl = 2.1 x Purchase Cost — 15,341

$$L = \sqrt{(4.095 \times 10^{-3}) Q_{fl.g.}^{scfm} \times CHV_{fl.g.}^{scf} - H^2} \qquad 148$$

Total Piping Costs
Aug. 1978 $, Cp (See Tables 17 and 19) — 4,462
source leg: $2,262 pipe leg: $2,200

Total Ducting Costs
Aug. 1978 $, Cd — 0

June 1980: Installed

Piping = $Cp \times \frac{329.3}{273.1} = Cp \times 1.206$ — 5,381

Ducting = Cd $\times \frac{291.3}{226.2}$ = Cd x 1.288 — 0

Flare = Cfl $\times \frac{259.2}{226.2}$ = Cfl x 0.818 — 12,549

TOTAL, C sys = (Cp + Cd + Cfl) — 17,930

Capital Recovery = Cfl x 0.1315 + (Cp + Cd) x 0.1627 — 1, 2,526

Operating Costs

Operating Labor — 2, 11,160

Maintenance — 3, 897

Utilities

$\left(\frac{\text{scfm}}{\text{Q n.g.}}\right)$ pilot = 80 scfh, if $2 \leq D \leq 8$

= 160 scfh, if $10 \leq \leq 20$ — 80 scfh

= 240 scfh, if $D \geq 24$

$\left(\frac{\text{scfh}}{\text{Q n.g.}}\right)$ purge = $0.372 \times D^2 - \left(\frac{\text{scfm}}{\text{Q fl.g.}}\right) \times 60$ — 0 scfh

Note: if ≤ 0, select 0

Cost natural gas, C n.g. = 3,149 $\left(\frac{\text{scfm}}{\text{Q n.g.}}\right)$ aux. + 53.45 $\left(\frac{\text{scfh}}{\text{Q n.g.}}\right)$ pilot + $\left(\frac{\text{scfh}}{\text{Q n.g.}}\right)$ purge — 4, 4,276

Cost steam, steam = 3.296 $\left(\frac{\text{scfm}}{\text{Q fl.g.}}\right)$ x MW fl.g. x $\frac{\text{wt \% HC}}{100}$ — 5, 28,465

Taxes, Insurance, etc. = C sys x 0.04 — 6, 717

TOTAL ANNUALIZED COSTS = 1 + 2 + 3 + 4 + 5 + 6 — 48,041

Table 17. PIPING AND DUCTING DESIGN PROCEDURE

Item	Value
(1) Pipe diameter, D	
(a) Piping[a]	For Source Legs: D (in.) = 0.042 x Q (scfm) + 0.472, for Q < 40 scfm D (in.) = 0.009 x Q (scfm) + 2.85, for 40 ≤ Q < 700 scfm For Pipeline Legs: D (in.) = 0.024 x Q (scfm) + 0.549, for Q < 65 scfm D (in.) = 4.8 $\log_{10}$ [Q (scfm)] - 7.33, for 65 ≤ Q < 700 scfm Select next larger inner diameter of schedule 40 pipe (given in Table E-19) unless calculated size with 10 percent of interval to next larger size.
(b) Ducting[b]	D (in) = (0.3028) $\sqrt{Q(acfm)}$, for D > 12 in. or Q ≥ 700 scfm and Q ≤ 60,000 acfm D (in.) = (0.1915) $\sqrt{Q(acfm)}$, for Q > 60,000 acfm Select size that is a multiple of 3 inches.
(2) Pipe length, L	
(a) Flares	Assumed 70-ft. source leg from each source to the pipeline. Assumed separate pipelines for large (≥ 35,000 scfm) intermittant streams and for all continuous streams together. Selected pipeline length of 70, 500 or 2,000 ft. if calculated safe pipeline length within 10 percent of standard length; if not, selected calculated length between standard values.
(b) Incinerators	Assumed 70-ft. source legs from each source to the pipeline. Used duct, fan, and stack cost from Enviroscience (Reference 28) which assumes a 150-ft. duct cost based on the GARD Manual (Reference 64).

[a]Economic pipe diameter equations from Reference 62 (which is based upon References 59 and 60).

[b]From continuity equation $Q = \frac{\pi}{4} D^2 V$; assumed velocity, V, of 2,000 fpm for lower flows and 5,000 fpm for higher flows.

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Table 19. INSTALLED PIPING COSTS[a]

Pipe Diameter (ft)	Cost in August 1978 Dollars for Pipe Leg Type			
	(70 ft) Source Leg	(20 ft) Compressor Leg	500 ft Pipeline	2,000 ft Pipeline
0.0411	2,200	1,050	2,275	4,360
0.0518	2,262	1,085	2,555	4,955
0.647	2,330	1,120	2,660	5,255
0.0874	2,470	1,170	2,870	5,800
0.1342	2,725	1,375	3,485	7,235
0.1722	3,340	1,490	3,990	8,190
0.2057	5,644	2,725	5,765	10,690
0.2557	6,045	2,900	6,640	12,500
0.2957	7,428	3,465	7,925	14,825
0.3355	7,786	3,830	9,000	16,870
0.4206	9,750	4,800	11,080	21,430
0.5054	11,415	5,570	13,220	26,120
0.6771	16,025	7,715	17,865	34,545
0.8542	23,925	11,440	26,500	48,920
1.021	33,133	18,280	36,320	65,000
1.111	45,750	20,900	48,680	83,400
1.281	58,680	26,670	61,554	96,850
1.448	72,800	32,670	77,450	123,200
1.604	92,581	41,140	97,010	149,420
1.937	121,200	54,205	124,075	186,385

[a] From SOCMI-Distillation NSPS Computer Program "DM Pipe" (Reference 63) based on component costs from Reference 30.

CALCULATIONS: INCREASE FLARE COSTS

o Capital Cost

	100' Flare	30' Flare
	$53,838	$12,549
	(from equation on p. 3 of flare worksheet)	
Annualized Capital Recovery (@ 0.1315)	$ 7,080	$1,650
Taxes, Ins. and Admin. (@ 0.05)	$ 2,692	$ 627
Maintenance (@ 0.04)	$ 2,154	$ 502
	$11,926	$2,779
Total (Annual)	$57,188	$48,041
Emission Reduction (Tons)	3,266	3,266
Cost Effectiveness ($/ton)	17.5	14.7

o MAINTENANCE @ 8% (Flare + piping) $4,738 $897

Total (Annual)	$59,557	$48,041
Emissions Reduction (Tons)	3,266	3,266
Cost Effectiveness ($/ton)	18.2	14.7

o ENCLOSE FLARE

$$\frac{\$15/\text{ton}}{\$100/\text{ton}} = \frac{\$18.2/\text{ton}}{\$/\text{ton}}$$

$$\$/\text{ton} = \frac{\$100/\text{ton}}{\$15/\text{ton}} \times \$18.2/\text{ton} = \$121/\text{ton}$$

TELEPHONE CONVERSATION REPORT

File/Charge # 727
DATE March 11, 1985

TIME AM [X] PM [ ]
Incoming Call [ ]
Outgoing Call [X]

Person Ed Fowler
Organization National AirOil Burner
Address Pennsylvania

Telephone 215-743-5300
By Ken Meardon

Subjects Discussed I asked Mr. Fowler whether the constituents in the emission stream would pose any problems in flaring the stream. Mr. Fowler noted that SO_2 and CO are toxic gases and would be subject to local and Federal regulation. Mr. Fowler noted that MMA can polymerize very easily and therefore one needs to be aware that pluggage of the flare header can occur. He noted that more frequent maintenance of the flare header and the valves might be required to prevent any pluggage that might occur. This more frequent maintenance might be in the range of cleaning the flare header once every year or two rather than essentially no cleaning at all, which might be the case if no polymerizable material were present. Mr. Fowler noted that in the end he did not think the presence of MMA would preclude or prevent the flaring of the gas stream.

I then asked Mr. Fowler about noise - if it were a problem, how might it be reduced? Mr. Fowler noted that there are three sources of noise - steam, combustion, and jet noise. Steam noise can be reduced by using accoustical treatment in the flare header. Combustion noise can be reduced by increasing the flare hieght above the ground. An expensive alternative would be to enclose the flare. Mr. Fowler made a ballpark guess that if the emission reduction cost $15 per ton of VOC reduced, an enclosed flare might result in a cost of $100 per ton. Mr. Fowler did not think jet noise would be a problem at a velocity of 52 feet per second. If jet noise is a problem, it can be reduced by using a larger head on the flare. Finally, Mr. Fowler noted that a flare for this stream should not use any liquid seals because (1) they would help the MMA to polymerize and (2) the presence of SO_2 and the liquid would result in sulfuric acid, which would corrode the base of the flare.

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APPENDIX F

Cost Analysis for Individual Equipment Components

F.0 COST ANALYSIS FOR INDIVIDUAL EQUIPMENT COMPONENTS

F.1 INTRODUCTION

This appendix provides a basis for determining plant specific cost impacts for implementing RACT for equipment components. Chapter 5 presented cost impacts for three model plants of varying complexities (equipment populations); however, the actual cost impacts for any specific plant is dependent upon several factors. This appendix provides individual component impacts under two recovery credit scenarios and presents monitoring instrument costs to enable analysis of plant specific impacts and further to provide a basis for exempting plants with relatively few equipment components. In Section F.2, monitoring instrument costs are presented. Since the costs of monitoring instruments are shared by all plant equipment components that would be subject to RACT, the individual components cost to implement RACT presented in Section F.3 exclude the costs of monitoring instruments. Section F.4 presents the cost effectiveness of RACT as a function of plant complexity. The relationship between cost effectiveness and plant complexity is presented as the basis for the recommended small plant exemption from routine instrument monitoring.

F.2 MONITORING INSTRUMENT COSTS

RACT is based on equipment monitoring using the method specified in EPA Reference Method 21. Accordingly, any monitoring instrument that meets the specifications set forth in Reference Method 21 could be used. Reference Method 21 also allows owners or operators to test for leaks of certain equipment (e.g., equipment without rotating shafts) by use of a soap solution. Use of a soap solution where possible would reduce the amount of wear and, consequently, the maintenance necessary for monitoring instruments. Several monitoring instruments are available that comply with the specifications set forth in Reference Method 21.

The monitoring instrument costs presented in Chapter 5.0 are based on the assumption that plants will purchase two monitoring instruments to perform routine leak detection inspections. In actual practice, plants may purchase more or less, depending upon the number of equipment components found at the plant. It is assumed that two monitoring

instruments are sufficient to inspect approximately 3,000 equipment components on a quarterly basis.

F.3 INDIVIDUAL COMPONENT COST IMPACTS

This section presents individual component RACT cost impacts under two product recovery credit values to illustrate the effect of process stream type upon the cost effectiveness of RACT. Tables F-1 through F-4 present impacts for pressure relief devices, open-ended lines, valves, and pumps, respectively. The basis for the cost analysis is taken from the control techniques guideline document issued by the U.S. Environmental Protection Agency for synthetic organic chemicals and polymer manufacturing equipment.[1]

F.4 BASIS FOR SMALL PLANT EXEMPTION

Chapter 2 of this document explained that chemical processing plant VOC emissions from equipment components are a function of plant complexity (that is the type and number of each component), rather than based on plant throughput or capacity. However, small plants will typically have few equipment components and hence less potential emission reduction than large plants. Consequently, the cost effectiveness ($/Mg VOC emission reduction) to implement RACT for equipment components may be greater at small plants than large plants because there is less emission reduction to offset the costs of monitoring instruments needed to implement RACT.

The method used to estimate chemical processing plant costs to implement RACT was presented in Chapter 5, and costs were presented for three model plants. However, plant costs can be estimated by using the total number of valves in gas and light liquid service as a simplified measure of plant complexity. Mathematically, the simplified relationship between plant complexity and RACT cost effectiveness can be expressed in the equation:

$$\frac{\text{Net annualized instrument cost} + \left[\left(\begin{array}{c}\text{Number of}\\ \text{valves}\end{array}\right)\left(\begin{array}{c}\text{Net annualized}\\ \text{cost per valve}\end{array}\right)\right]}{\left(\begin{array}{c}\text{Emission Reduction}\\ \text{per valve}\end{array}\right)\left(\begin{array}{c}\text{Number of}\\ \text{valves}\end{array}\right)} = \begin{array}{l}\text{Cost effectiveness}\\ \text{\$/Mg VOC reduction}\end{array}$$

As an example calculation, consider the cost effectiveness for a plant with 1,000 gas service and 1,000 light liquid service valves under the average case scenario:

Emission reduction: gas service = 0.030 Mg/yr
light liquid service = 0.027 Mg/yr
Weighted average:

$$\frac{(1000)(0.030\ \text{Mg/yr}) + (1000)(0.027\ \text{Mg/yr})}{2000\ \text{total valves}} = 0.0285\ \text{Mg/yr}$$

Net annualized costs:
gas service = - $4.68/valve
light liquid service = - $3.14/valve
Weighted average:

$$= \frac{(1,000)(-\$4.68) + (1,000)(-\$3.14)}{2,000\ \text{total valves}} = -\$3.91.$$

Substituting in the equation:

$$\frac{\$7,130/\text{yr} + [(2,000)\ (-\$3.91/\text{yr})]}{(0.0285\ \text{Mg/yr})(2,000)} = x = \text{cost effectiveness}$$

$$\$7,130/\text{yr} - \$7,820/\text{yr} = (57\ \text{Mg/yr})(x)$$

$$-\$12/\text{Mg} = x$$

The relationship between plant complexity and RACT cost effectiveness is graphically illustrated in Figure F-1. Figure F-1 shows that the cost effectiveness to implement RACT increases rapidly as plant complexity decreases to less than about 400 valves. The point at which the cost effectiveness becomes unreasonable occurs between 150 and 400 valves. Figure F-1 presents RACT costs under six scenarios:

LA: all valves in light liquid service with average product value
GA: all valves in gas service with average product value
WA: weighted average service (50 percent light liquid, 50 percent gas) with average product value
LL: all valves in light liquid service with low product value
GL: all valves in gas service with low product value
WL: weighted average service (50 percent light liquid, 50 percent gas) with low product value.

Table F-1. PRESSURE RELIEF DEVICE IMPACTS
(December 1984 Dollars)

Cost Item per Relief Device	Quarterly Leak Detection and Repair	
	APV Service	LPV Service
Installed Capital Cost[a]	0	0
Annualized Capital Costs[a]		
A. Control Equipment[a]	0	0
B. Initial Leak Repair[b]	0	0
Annualized Operating Costs		
A. Maintenance[a]	0	0
B. Miscellaneous[a]		
1. Monitoring[c]	28	28
2. Leak Repair[b]	0	0
3. Administrative and Support[d]	11	11
Total Annual Costs Before Credit	39	39
Recovery Credit[e]	(248)	(72)
Net Annualized Costs[f]	(209)	(33)
Total VOC Emission Reduction (Mg/yr)[g]	0.40	0.40
Cost Effectiveness[h] ($/Mg VOC)	(520)	(82)

(xx) = Cost Savings.
APV = Average Product Value.
LPV = Low Product Value.

[a] Cost of monitoring instrument is not included in this analysis.

[b] Leaks are corrected by routine maintenance in the absence of regulatory controls, therefore, no additional cost is incurred for repairs.

[c] Monitoring labor hours (i.e., number of workers x number of components x times monitored per year) x $26 per hour. Hourly labor rate based on updating a May 1980 labor rate ($18/hr) to December 1984. Costs assume 2-man monitoring team per relief valve, 8 minutes monitoring time per relief valve. Reference 1, p. 5-7.

[d] Estimated at 40 percent of monitoring and leak repair cost.

[e] Recovery credits are based on $620/Mg emission reduction for equipment in average product value service or equivalent to isopropyl alcohol service and $180/Mg for equipment in low product value equivalent to methanol service. Reference 2. Isopropyl alcohol represents an average product recovery credit for chemical processing plants. Updating the value used in reference 1 ($429/Mg in second quarter 1980 dollars x cost index of 1.45 = $620 in December 1984 dollars) results in a value of $620/Mg. References 1 and 3. Methanol service streams are representative of low recovery credit streams and, hence, represent a worst case recovery credit. A detailed discussion of product recovery values is presented in Appendix A of reference 4.

[f] Total annualized cost (before credit) minus recovery credit.

[g] From Table 3-1.

[h] Obtained by dividing net annualized cost by total VOC emission reduction.

Table F-2. OPEN-ENDED LINES IMPACTS
(December 1984 dollars)

Cost Item per Open-ended Line	Cap, Plug, Flange, or Second Valve	
	APV Service	LPV Service
Installed Capital Cost[a]	76	76
Annualized Capital Costs Control Equipment[b]	12.4	12.4
Annualized Operating Costs		
A. Maintenance[c]	3.9	3.9
B. Miscellaneous[d]	3.0	3.0
Total Annualized Costs	19.3	19.3
Recovery Credit[e]	(9.3)	(2.7)
Net Annualized Costs[f]	10.0	16.6
Total VOC Emission Reduction (Mg/yr)[g]	0.015	0.015
Cost Effectiveness[h] ($/Mg VOC)	670	1100

(xx) = Cost Savings.
APV = Average Product Value.
LPV = Low Product Value.

[a] Updated using cost indexes. Based on purchase of a second valve. References 1 and 3.

[b] Based on 10 percent interest and 10-year life. Calculated as 0.163 (capital recovery factor) x capital cost.

[c] Calculated as 0.05 x capital cost. Reference 1, p. 5-7.

[d] Calculated as 0.04 x capital cost. Reference 1, p. 5-7.

[e] See footnote e of Table F-1.

[f] Total annualized cost (before credit) minus recovery credit.

[g] Based on uncontrolled emission factor of 0.0017 kg/hr and 100 percent control efficiency. Reference 1.

[h] Obtained by dividing net annualized cost by total VOC emission reduction.

Table F-3. VALVE IMPACTS
(December 1984 dollars)

Cost Item per Valve[a]	Quarterly Leak Detection and Repair			
	Gas Service		Light Liquid Service	
	APV	LPV	APV	LPV
Initial Leak Repair[b]	0.76	0.76	0.44	0.84
Monitoring Labor[c]	3.94	3.94	3.94	3.94
Recurring Leak Repair Labor[d]	5.46	5.46	5.46	5.46
Administration and Support[e]	3.76	3.76	3.76	3.76
Total Annualized Cost	13.92	13.92	13.60	13.60
Product Recovery Credit[f]	(18.60)	(5.40)	(16.74)	(4.86)
Net Annualized Cost[g]	(4.68)	8.52	(3.14)	8.74
Total VOC Emission Reduction[h] (Mg/yr)	0.030	0.030	0.027	0.027
Cost Effectiveness ($/Mg VOC)	(160)	280	(120)	320

(xx) = Cost Savings.
APV = Average Product Value.
LPV = Low Product Value.

[a] Cost of monitoring instrument is not included in this analysis.

[b] Calculated as:

number of components x initial leak frequency x 1.13 hrs/valve x $26/hr x 1.4 x 0.163.

Initial leak frequency for gas service valves = 11.4 percent and for light liquid service valves = 6.5 percent. Reference 1, p. 5-5.

[c] Calculated as:

$$\text{Fraction of Sources Screened} \times \frac{1 \text{ min}}{\text{valve}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{\$26.00}{\text{hr}} \times 2 \text{ workers}$$

Fraction of sources screened = 3.94. Reference 1, p. 5-8.

[d] Calculated as:

$$\text{Fraction of Sources Operated on} \times \frac{1.13 \text{ hrs}}{\text{valve}} \times \frac{\$26.00}{\text{hr}}$$

Fraction of Sources operated on = 0.186. Reference 1, p. 5-8.

[e] Based on 40 percent of monitoring labor and recurring leak repair labor. Reference 1.

[f] See footnote e of Table F-1.

[g] Total annualized cost (before credit) minus recovery credit.

[h] Reference 1, p. 3-3.

Table F-4. PUMP SEAL IMPACTS
(December 1984 dollars)

Cost Item per Pump (seal)	Quarterly Leak Detection and Repair	
	APV Service	LPV Service
Initial Repair[a]		
Labor[b]	8.35	8.35
Replacement Seals[c]	2.89	2.89
Maintenance - ongoing	78.80	78.80
Replacement Seals[d]		
Monitoring Labor	17.30	17.30
Instrument[e]	11.30	11.30
Visual[f]		
Recurring Repair Labor[g]	164	164
Administration and Support[h]	77.00	77.00
Total Annualized Cost	359.64	359.64
Product Recovery Credit[i]	(87.42)	(25.38)
Net Annualized Cost[j]	272.22	334.26
Emission Reduction (Mg/VOC yr)[k]	0.141	0.141
Cost Effectiveness ($/Mg VOC)	1,930	2,370

(xx) = Cost Savings.
APV = Average Product Value.
LPV = Low Product Value.

[a] Pump seal repair costs are based on 16 labor hours per pump repair and include $200 per repair for a replacement seal. This analysis does not include the cost of a monitoring instrument.

[b] Calculated as:

estimated percent of initial pumps leaking (Reference 1, p. 5-5)	x	labor hours per seal repair	x	labor rate	x	administration and support costs	x	capital recovery factor

0.088 x 16 hrs/seal x $26/hr x 1.40 x 0.163

Table F-4 footnotes (concluded)

Net Annualized Cost[j]	272.22	334.26
Emission Reduction (Mg/VOC yr)[k]	0.141	0.141
Cost Effectiveness ($/Mg VOC)	1,930	2,370

(xx) = Cost Savings.
APV = Average Product Value.
LPV = Low Product Value.

[a] Pump seal repair costs are based on 16 labor hours per pump repair and include $200 per repair for a replacement seal. This analysis does not include the cost of a monitoring instrument.

[b] Calculated as:

estimated percent of initial pumps leaking (Reference 1, p. 5-5) x labor hours per seal repair x labor rate x administration and support costs x capital recovery factor

0.088 x 16 hrs/seal x $26/hr x 1.40 x 0.163

[c] Initial replacement seal cost is calculated as:

Estimated percent of of initial pumps leaking x replacement seal x capital recovery factor

Initial percent of pumps leaking = 8.8 percent. Reference 1, p. 5-5.

[d] Ongoing replacement seal cost is calculated as:

Fraction of sources repaired x $200/replacement seal

Fraction of sources repaired on quarterly LDR = 0.394. Reference 1, p. 5-8.

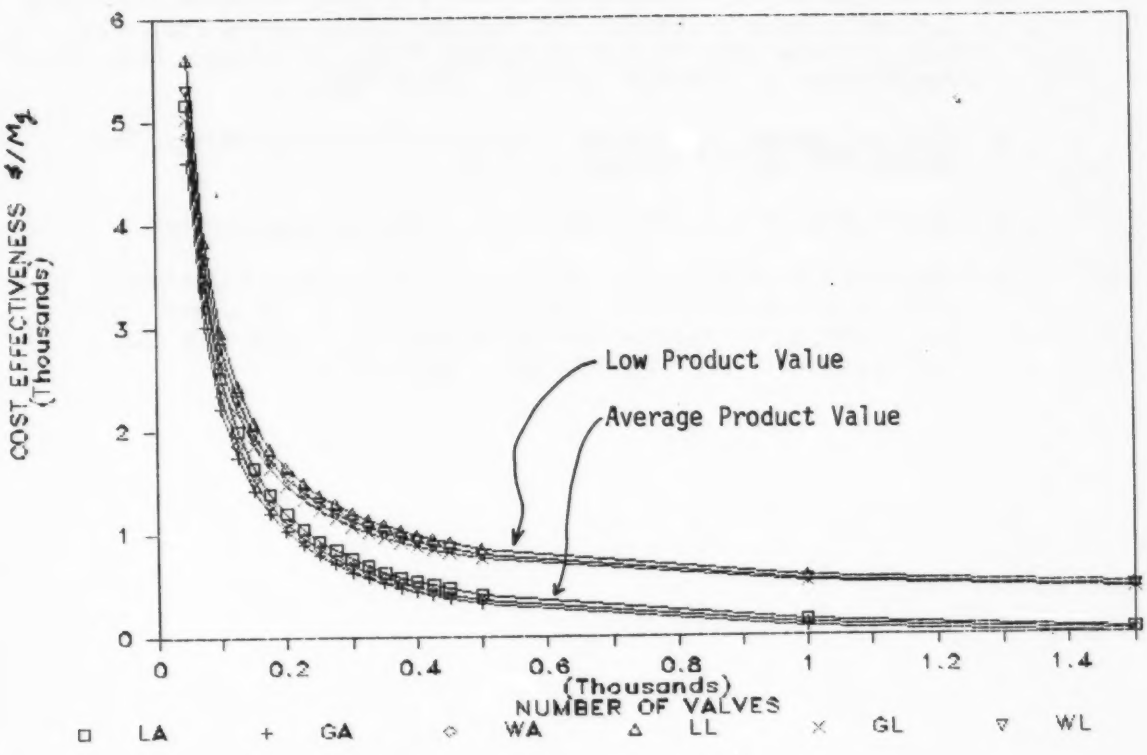
[e] Calculated as:

$$\text{Fraction monitored} \times \frac{5 \text{ min}}{\text{pump seal}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{\$26}{\text{hr}} \times 2 \text{ workers}$$

Fraction monitored = 4, for quarterly monitoring.

[f] Calculated as:

$$\text{Fraction monitored} \times \frac{0.5 \text{ min}}{\text{pump seal}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{\$26}{\text{hr}} \times 1 \text{ worker}$$



LA: all valves in light liquid service with average product value
GA: all valves in gas service with average product value
WA: weighted average service (50 percent light liquid, 50 percent gas) with average product value
LL: all valves in light liquid service with low product value
GL: all valves in gas service with low product value
WL: weighted average service (50 percent light liquid, 50 percent gas) with low product value.

Figure F-1. GRAPH OF THE RELATIONSHIP BETWEEN PLANT COMPLEXITY AND RACT COST EFFECTIVENESS

F.5 REFERENCES

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4. Fugitive Emission Sources of Organic Compounds -- Additional Information on Emissions, Emission Reductions, and Costs. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-82-010. April 1982.